SILICONE COATED INSULATORS

FAQ between field experience and testing

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A lot has been said and written about silicone coated insulators and their performance. SEDIVER has extensively published on the topic either through INMR, IEEE, CIGRE or other technical expert communities. Currently IEC is working on an important new standard (future IEC 63432) to establish a consensus for formal procedures and testing protocols based on a large, accumulated mass of testing and field experience gained over decades [1]. This paper intends to cover a few topics some of them corresponding to frequently asked questions less obvious than those covered in previous communications. It also comes as an addition to the previous INMR publication [3] focusing on ageing and end of life of coatings.

1. Hydrophobicity transfer and recovery properties

These are two definitions often mixed up. By nature, hydrophobicity is a property of silicone materials which can be assimilated to a water repellency property. For materials such as silicone, this property is dynamic and can evolve as a function of the environmental stress conditions. For example, when a silicone surface is subjected to maintained dry band arcing or corona activity this hydrophobicity is stopped and while sometimes this loss can be permanent, usually the hydrophobic property can recover after some time. This is the **recovery** property.

On another hand, once the silicone insulator is exposed to external pollution, the surface is progressively covered with dust or other environmental pollutants. Obviously, the crust of pollutant is not usually hydrophobic, but silicone has this unique ability to contain low weight molecular species able to migrate through the crust of pollutant and make the deposit layer itself become hydrophobic. This is the **transfer** property.

The transfer property is of course key in the reason why silicone is an interesting material for polluted environments. Without this property silicone would be useless and would be unable to act differently than glass or porcelain surfaces. Nevertheless, there is an important consequence of this property when it comes to the evaluation of the pollution layer over a silicone surface. The fact that

progressively the pollutant is encapsulated in the silicone bulk material results in a relatively reduced amount of pollutant collected when measuring the ESDD/NSDD.
A recent study performed in the Sediver Research Center has shown that comparatively RTV silicone coated insulators have a slightly faster transfer time than commercially available silicone HTV used in polymer insulators. This is the result of structural differences between the two chemistries. Figure 1 shows test data from surfaces polluted with Kaolin at ESDD=0.1mg/cm² and NSDD= 0.2mg/cm².

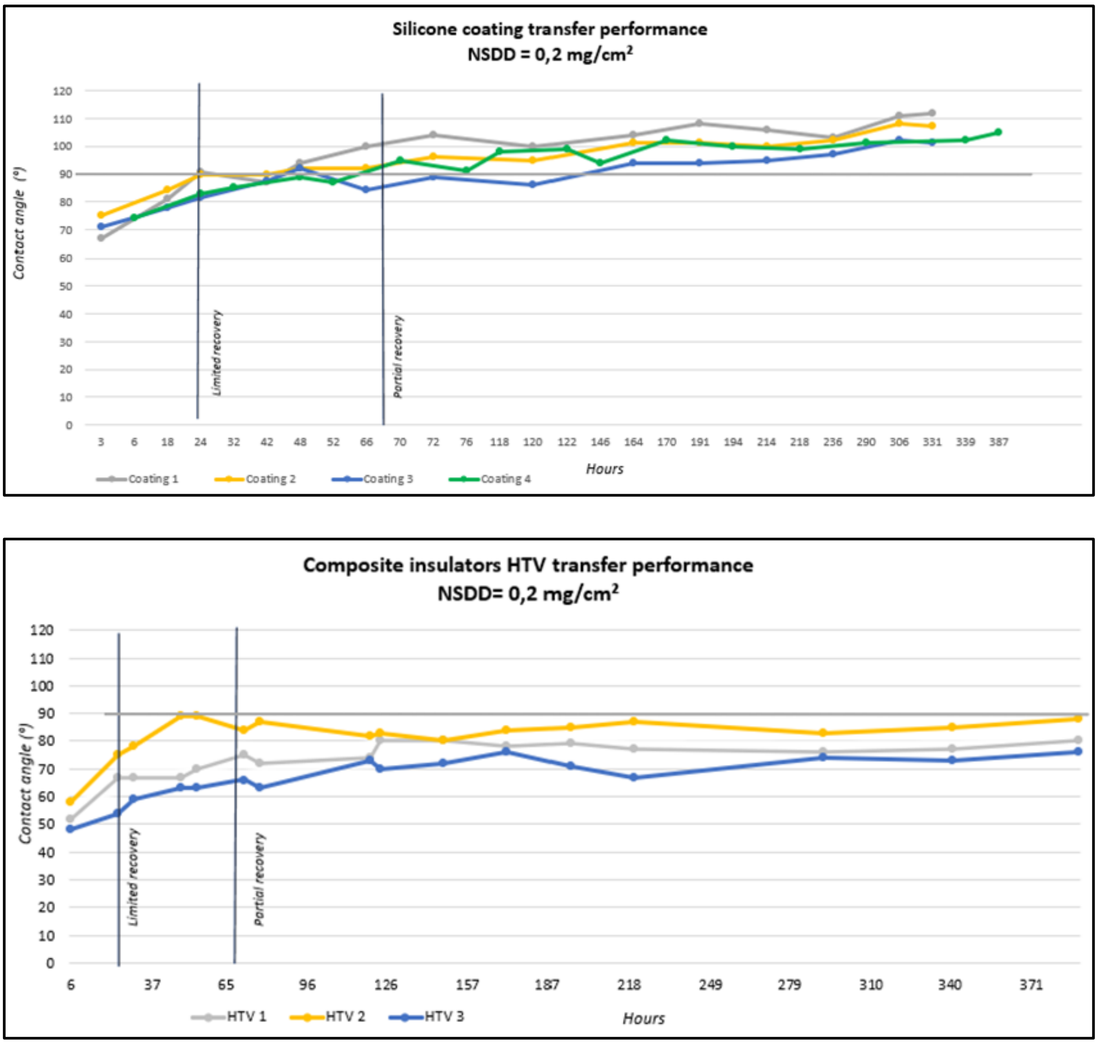


Figure 1: contact angle as a function of time (in hours) measured during hydrophobicity transfer on RTV silicone coatings (top) and HTV silicone (bottom) at ESDD=0.1mg/cm² and NSDD=0.2mg/cm²

As a matter of fact, the upcoming IEC 63414 standard [2] describing test procedures for artificial pollution tests on HTM insulators stipulates that the solid layer pollution tests should be performed within 24h after the deposit of the layer if the goal is to determine the performance of an insulator with limited recovery and within 64h to 68h for a test with partial recovery.
In the upcoming IEC 63414 [2] there is also a provision about the maximum NSDD level to consider for testing. If Kaolin is used the limit is NSDD=0.25mg/cm² and with Tonoko it is NSDD=0.4mg/cm², Tonoko being known to be impacting less than Kaolin the conductivity of the pollutant layer on the surface of an insulator. This is important with respect to some demands made by engineers who want sometimes an artificial pollution test performed with very high NSDD levels, sometimes above

1mg/cm² or even 2mg/cm². It is completely unrealistic to produce such tests because the transfer cannot take place in a realistic time scale, and it is not representative of the reality where, in the field, pollution accumulates progressively, and hydrophobicity rebuilts itself progressively too. The example in Figure 2 illustrates the dynamics at play in the pollution layer itself with an evolution of performance over time of approximately 25% over a period slightly above 1month.

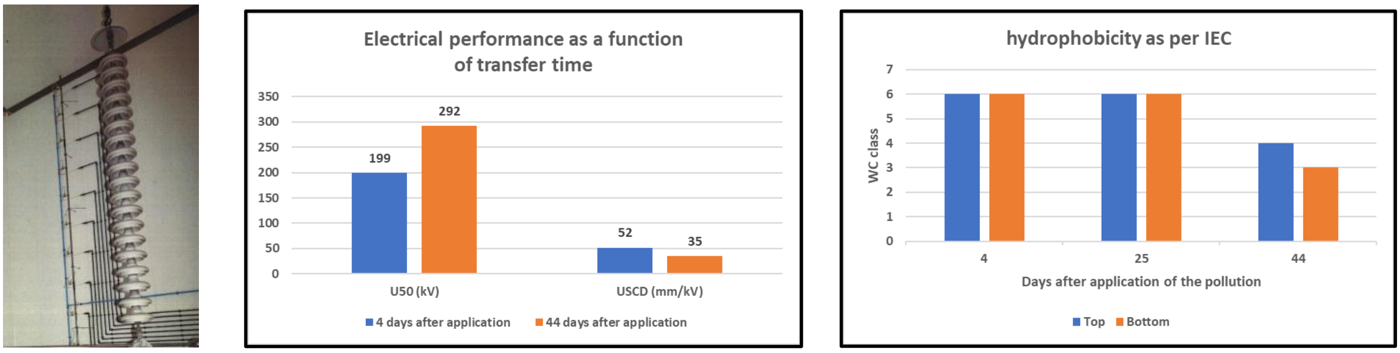
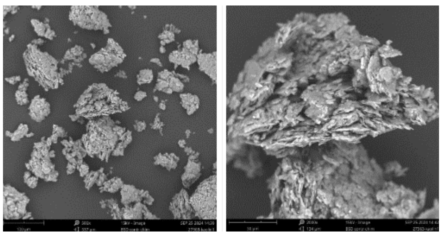
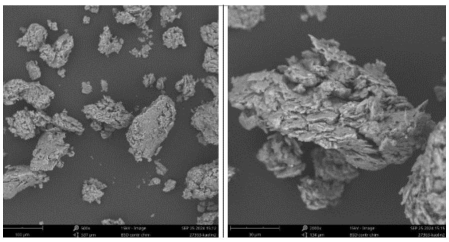


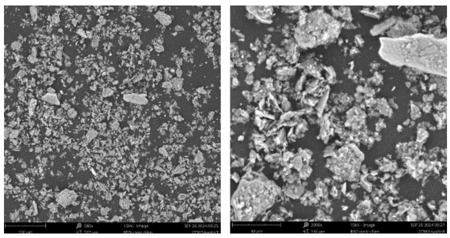
Figure 2: evolution of the pollution performance in DC of a string of 19 coated glass insulators tested at ESDD=0.4mg/cm² and NSDD=1mg/cm². Right shows WC hydrophobicity class over time.

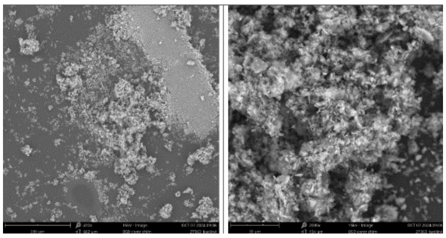
2. Accuracy of ESDD/NSDD sampling on silicone surfaces

Another question related to the transfer property of silicone is to quantify the level of pollution on an insulator in service. This technique is well known and largely used for the evaluation of pollution on site, in test stations…but the transfer of hydrophobicity will progressively encapsulate the pollutant itself and alter the accuracy of the evaluation of the pollution level through the usual method of collection of dust by washing. An investigation made in the SEDIVER Research Center on a variety of kaolin species is reported below in figure 3. Type 1 is the common kaolin used for pollution test and has properties in accordance with IEC 60507. Type 2 to 4 were made with a kaolin having a granulometry below the IEC recommendation but can be compared to some thin dust particles such as thin dust in desertic environments. Type 5 is Kieselguhr.


Ref; Kaolin type 1 as per IEC 60507


Kaolin type 2


Kaolin type 3


Kaolin type 4

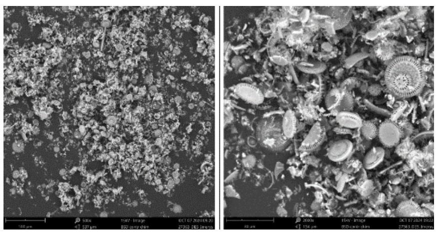

Kieselguhr type 5

Figure 4: SEM pictures of diverse types of kaolin used for the study of encapsulation of dust in silicone. (Magnification X500 Image on the right and X2000 Image on the left)

Slurries made with these different types of contaminants were applied on slabs of silicone coated tiles as shown in figure 5 by dipping. The level of pollution on the slabs was set as "Heavy" in the IEC60815-1 classification. One slab for each type was made to be used as a reference to measure the ESDD/NSDD at the beginning of the test.

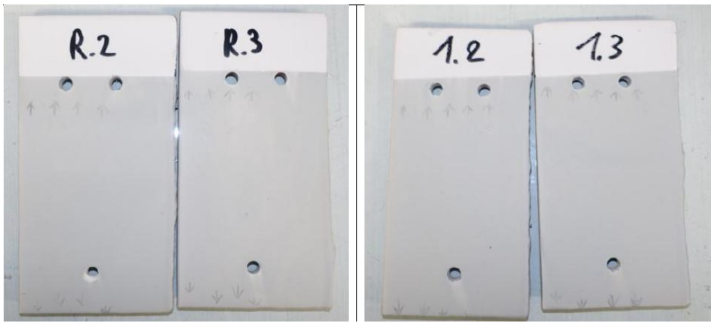


Figure 5: slabs prepared for a pollution deposit with the various types of kaolin

After 70 days the slabs were cleaned to evaluate the ESDD and NSDD levels and compared with the values from a reference slab which was initially polluted together with the test samples. As can be seen in figure 6 a typical pattern common to all types of kaolin tested shows that the silicone surface will retain most of the NSDD while the ESDD would typically be largely removed during this cleaning phase but not completely. This means that cleaning a silicone surface to measure the ESDD/NSDD in the field will provide a NSDD largely underestimated while the ESDD can be considered as slightly reduced.

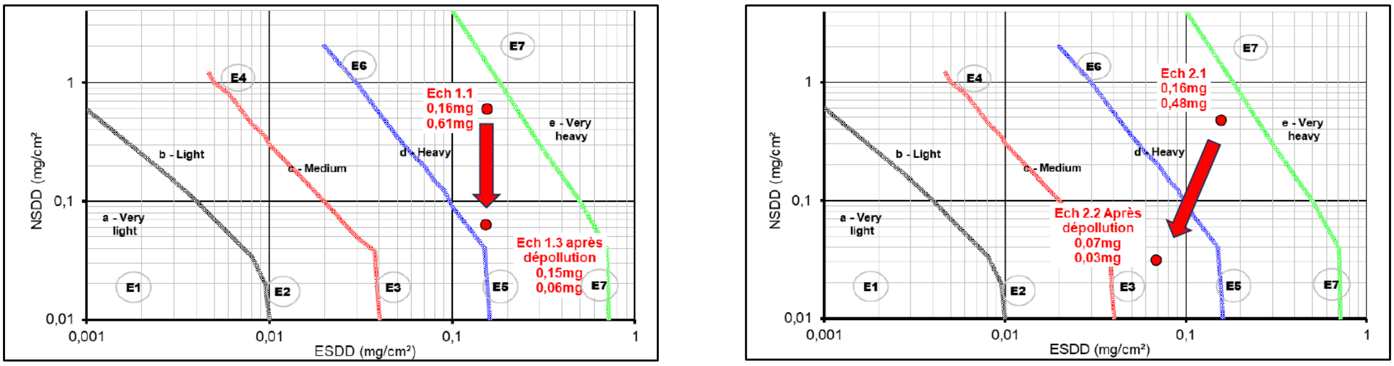


Figure 6: left graph shows a sample where the encapsulation of the kaolin provides a wrong level of NSDD while the ESDD collected from the sample is correct. Right shows a case where the ESDD collected from the sample is also reduced compared to reality.

To further validate the finding SEM pictures were made on the slabs after they were cleaned to remove the pollution from the surface. Figure 7 shows the surface of a few samples consistent with all the test samples made during this test. Large quantities of the original minerals are still there, encapsulated in the silicone surface and therefore are not accounted for during the measure of NSDD but also to a lesser degree to the ESDD.

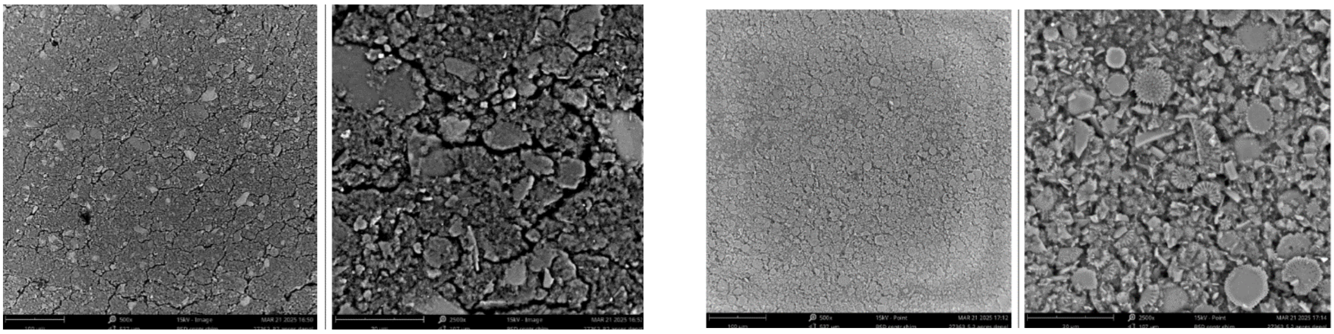


Figure 7: surface of type 1 (left) and type 5 (right) after the depollution cleaning process. (Magnification X500 Image on the right and X2500 Image on the left for each type)

3. Electric field simulation of coated insulators

This question is frequently being asked. It is a legitime question from a theoretical point of view, but it is important to keep in mind that hydrophobicity is a dynamic process, unpredictable and always with heterogeneity along the surface of the insulator, even if the higher electric stress is by nature located around the pin. The previous sections have shown how difficult it is to describe theoretically the dynamic evolution of silicone in service.
Figure 8 shows the model used for the electric field simulation of a silicone coated glass insulator for a short string. The calculation was processed through COMSOL.

A string of five fog type insulators were modeled with a 350µm of silicone over the glass and the string energized at 80kV.

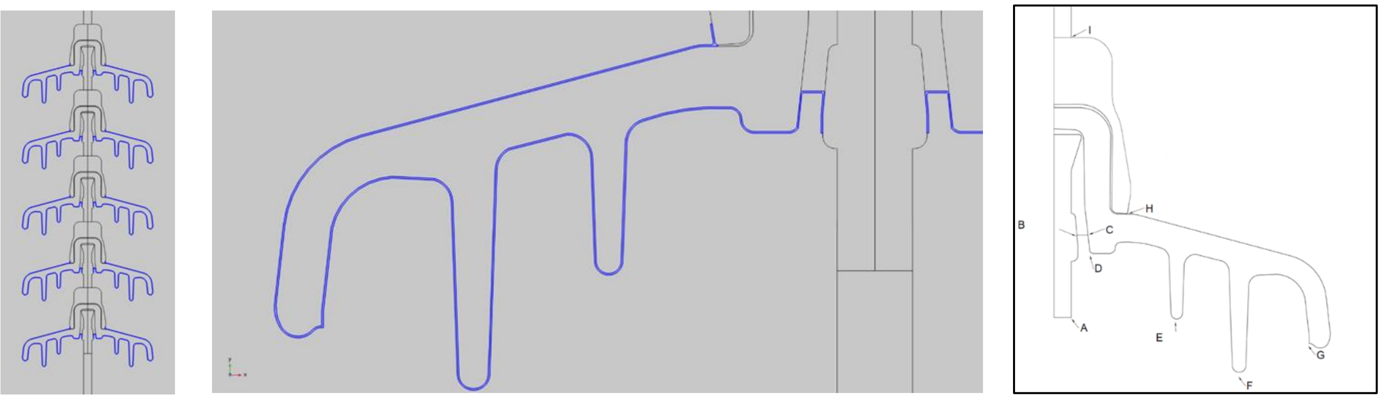


Figure 8: modelisation of a string of 5 insulators coated with silicone.

The evaluation of the voltage gradient was determined and compared to the values of a non-coated string of insulators. Figure 9 describes the potential distribution on each of the five units and it appears clearly that there is no significant difference if silicone is added to the surface or not.

Likewise, the electric field along the profile of the insulators is shown in figure 10 for the first two units which have the highest stress applied. Here again we see that there is no significant difference between the coated and non-coated units.

The evaluation of the E-field on coated insulators is therefore a useless exercise which brings no scientific or practical knowledge of importance, not mentioning that once the hydrophobicity varies it will become totally impossible to correctly model the insulator surface.

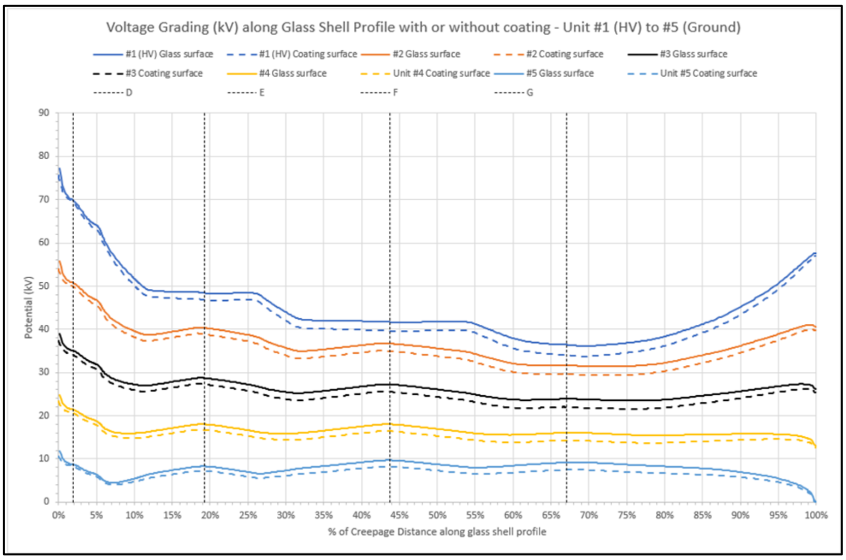


Figure 9: Potential along profile of each of the five (5) units, without (□) or with (- - -) coating

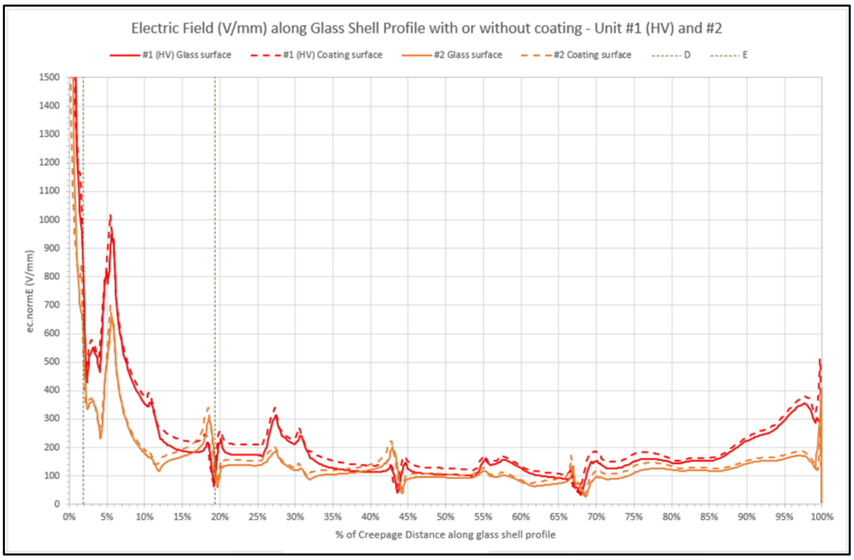


Figure 10: Electric Field along profile of units #1 and #2, without (□) or with (- - -) coating

4. How do coatings react to acids?

It is well known that polymer insulators can be severely damaged, up to a point of failure, when corona and electric arcing occurs and remains active along the core of an insulator. This results in erosion and cracking the of the sheath of the insulator which then can fail from acids such as nitric acid (generated by corona) degrading the fiberglass core.

The question is different for coated insulators since either glass or porcelain do not contain an organic fiberglass rod underneath and therefore will not fail because of the presence of acid. While this is one of the big benefits of silicone coated insulators compared to polymer insulators, the question of behavior of coating under an acidic environment is often being asked.

Of course, all coatings are not equally made, and chemistries can differ and display different reactions. The SEDIVER Research Center has evaluated the behavior of a variety of coatings under sulfuric acid and nitric acid. Figure 11 shows the condition of different types of silicone coatings after 100h and 200h in 1N concentrations of sulfuric and nitric acid at 50°C.

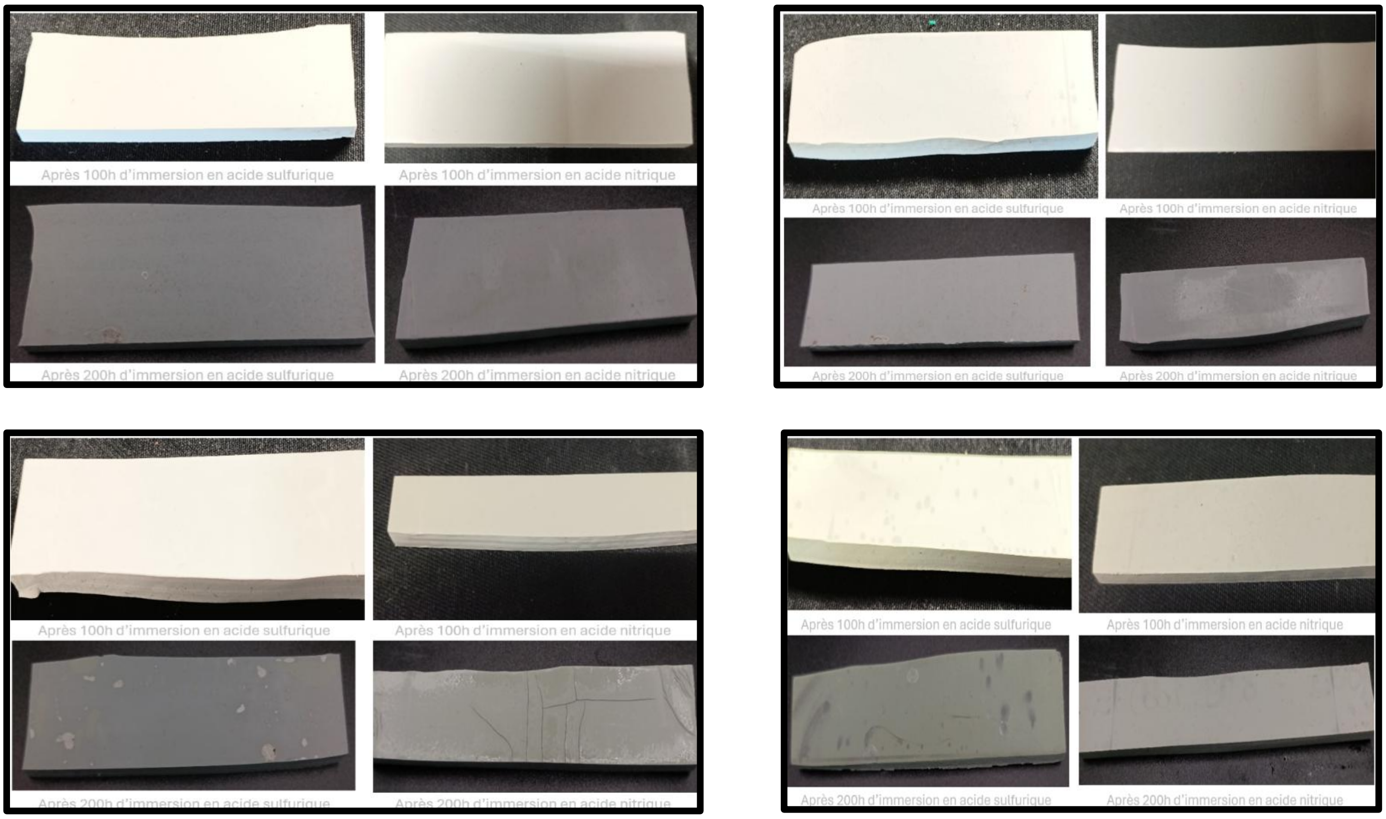


Figure11: visuals of 4 types of silicone coating material tested as slabs in 1N sulfuric and nitric acid. Each block of pictures shows at their left the test for sulfuric acid after 100h (top) and 200h (bottom). Right shows nitric acid after 100h (top) and 200h (left).

Only one out of the 4 chemistries showed obvious signs of degradations with cracks. But in reality, coatings seem less sensitive to acids than some HTV as can be seen in figure 12 from 3 commercially available HTV used in composite insulators. The biggest difference is the fact that even with cracks it has little if any impact on the behavior of a cap and pin suspension insulator since there is no fiberglass rod or organic interfaces underneath unlike a polymer insulator.

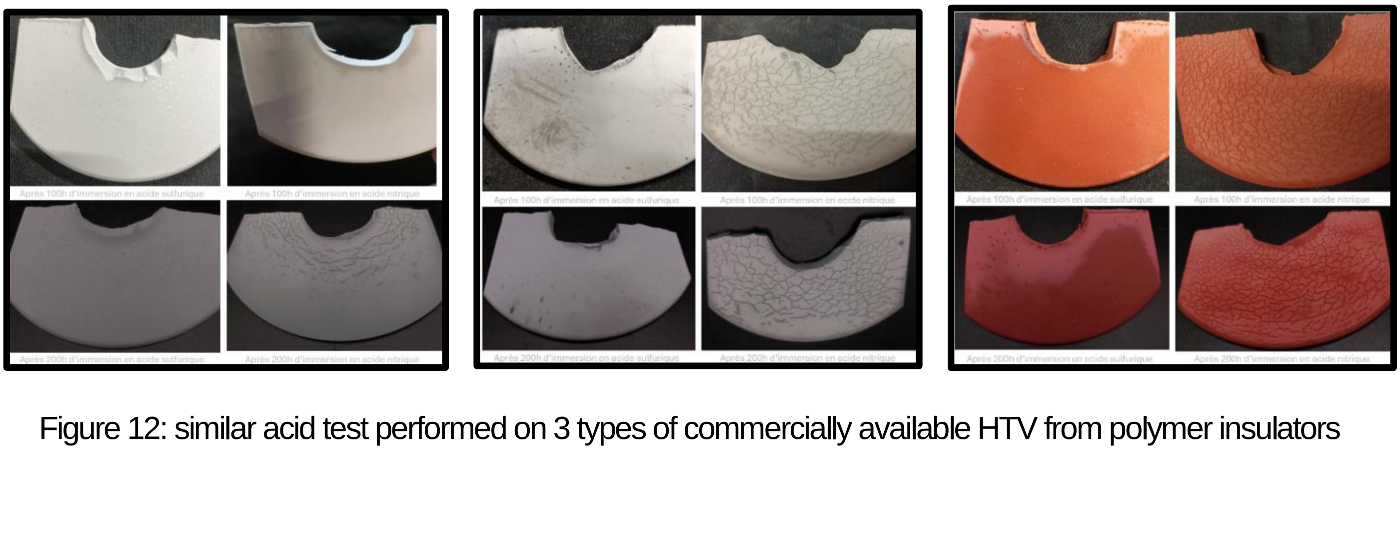


Figure 12: similar acid test performed on 3 types of commercially available HTV from polymer insulators

Table 1 below shows variations in hardness and hydrophobicity of the same types of silicone either RTV or HTV. There is no obvious rationality in the way to use such parameters to discriminate their benefits other than the visuals where one type of RTV (type 3) showed cracks and simultaneously shows the biggest change in hardness. But the HTV which were tested at the same time all showed cracks and while HTV3 shows severe degradations, it is the sample which hardness changes the least.
The changes in hydrophobicity measured through contact angle variations does not bring any value to the debate either, most of the samples have in fact a slight increase in hydrophobicity which is the result of the attack of the polymer itself.

Samples	Δ hardness (%)	Δ contact angle (%)
RTV 1	21	5
RTV 2	11	8
RTV 3	46	3
RTV 4	6	3
HTV 1	12	5
HTV 2	31	0
HTV 3	5	11

Table 1: changes in physical properties of the samples after 200h of exposure at 1N nitric acid

While checking such properties for HTV silicone chemistries used in polymer insulators can make sense because of the applied stress on the silicone either around the rod or at the base of the sheds during severe wind conditions, it is irrelevant for coatings which are applied on solid substrates.

5. Take aways.

This paper is intended to provide a few elements corresponding to frequently asked questions. Among the topics covered it is important to note the following:

- Understanding the effect of transfer properties is key in addressing pollution testing.
- Measuring ESDD/NSDD on silicone surfaces often leads to wrong data by under rating the reality given the encapsulation taking place with the transfer of hydrophobicity over the pollutants.
- Electric field simulation of silicone coated glass or porcelain insulators is useless and provides no benefit in the prediction of flashovers or pollution related performance.
- Acid tests on silicone coated insulators provides little interest even if some properties can change under an acid attack, mainly of nitric acid, but it is meaningless compared to the need for evaluation of the aging of HTV polymer insulators.

References

[1]: CIGRE Brochure 837 Coating for improvement of electrical performance of outdoor insulators under polluted conditions. June 2021
[2]: IEC 63414 Draft. Artificial pollution tests on high voltage polymeric insulators to be used on AC and DC systems.
[3]: INMR 2023 Bangkok. “Coating…of course”. JM George, S. Suc, F. Virlogeux.