

# Controlled volatility silicone conformal coatings: Why and how to use them

The fact that silicone products can affect sensitive electrical and electronic components is not a recent statement. Nowadays, almost all relay producers are writing on their technical datasheets that silicones should be avoided on their relays. However, these disclaimers do not consider recent developments in the field or potential designs that can prevent contamination issues with silicones.

The purpose of this article is not to hide potential issues, but to establish the facts and dispel the myths. It is aimed to clarify the situation by classifying and categorizing the different cases and their potential solutions.

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## Introduction

Today, protection of electronic circuits against harsh environment has become a real challenge. Electronics designers, often having an electronic engineering background, need to balance performance and cost of protective materials against process and capital expenditures. In order to make a sound decision, a basic understanding of protective chemicals is also required: what type of protection is needed? Is a conformal coating, an encapsulant, a gel or a sealant the best choice for this design? Which configuration is going to meet the specifications? Which material should one select? How can expensive failures in the field be minimized? The answers to these questions are not straightforward.

It is amazing to see that many engineers still base their decisions on somewhat outdated information: some designs exist for years, protected by the same pottant that was used decades earlier. In some cases, the use of a modern day conformal coating would be sufficient to achieve similar performance, at a lower cost. Such a switch could even result in a lighter electronic device.

Often, silicone coatings are actually cheaper to use than organic conformal coatings due to the fact that modern silicone conformal coatings are

'solventless'. Many believe that the thicker the layer, the better and the longer lasting the protection. However, this statement has to be considered in terms of the solid content, i.e. the dried or the cured layer of conformal coating. It is not advantageous to spend money on a solvent that does not contribute to the performance of the coating. Moreover, solvents contribute to emissions of volatile organic compounds (VOC) and require expensive extraction methods in production areas in order to meet the environmental legislations.

Overall, silicones represent 40 % of the global market value for conformal coatings. This may seem to be a significant market share, but considering the advantages of using silicone, why is silicone not used more broadly? If silicone conformal coatings could advantageously replace organic pottants, why are these materials still used? The answer can be provided in several parts:

1. The material cost is still considered as a barrier, even if the total production cost per unit protected is actually cheaper.
2. Many companies have grown accustomed to using their own protective materials and as such are reluctant to change.
3. Silicone-based materials still carry a bad reputation in terms of contamination

issues that have since been addressed.

The purpose of this article is to dispel the myths and establish the facts.

Interestingly, the commercial launch of silicone-based materials dates back to 1943, and the first article dealing with silicone contamination was published in 1944<sup>[1]</sup>. In the years following, more publications were issued on the same topic<sup>[2,3]</sup>. The following sentence from L.E. Moberly<sup>[4]</sup> sounds very contemporary: "With the increasing demands for high temperature materials, it is natural that silicones, whose retention of properties at high temperatures is well known, should be applied in many new equipment and apparatus designs...*(sic)*. The fact that silicone vapors affect the performance of contacts has been recognized for some time". Who would guess that this was written in 1960? These articles were published, years before silicone contamination issues were happening with relays in telecommunication and years before silicone contamination from the car painting industry. Although both cases are completely different, most people think that the root cause is the same. In reality the first case is caused by 'volatile contamination', while the second case is caused by

'fluid contamination'. There are several ways to resolve these issues and recent developments have addressed volatile and fluid contamination.

**Why are silicone-based conformal coatings so valuable?**

To properly answer this question, one must consider the following question: why are silicone materials so unique? To fully appreciate the answer, a closer examination of the chemical structure of the silicone polymer should be made (Figure 1). The core of a silicone polymer is comprised of a series of silicon oxygen Si-O bonds, which are very stable. The energy required to break a Si-O bond is about 110 kCal/mol, while the energy required to break carbon carbon C-C bonds is about 80 kCal/mol. The core of most organic polymers is made of carbon single bonds. This explains why silicones provide, in general, a better resistance to harsh environments than most organics.

In addition to the intrinsic property of silicones, the

energy to rotate the monomer units around each other is very low. Consequently, this polymer is very flexible. Its glass transition is quite low (-125°C) and so is its melting point (-60°C). As a result, from -60°C to its degradation temperature (>300°C), silicone materials display linear dependency of their physical properties, while most organic materials are facing either a transition temperature or degradation, which limits their service temperature or their performance.

One unique property of silicone polymer is related to its interaction with water. Silicones exhibit high water vapor permeability, combined with an excellent water-repellency. In terms of protection, this is the ideal scenario, as on one hand silicones are assisting the easy elimination of surface moisture on the substrate after application. On the other hand they protect the surface from any liquid water ingress. This exceptional behavior leads to another interesting property of these materials: the water absorption of

silicones at equilibrium is inferior to 0.1 %, while for organic materials it may vary from 0.3 % up to several percent. This large difference has an impact on the speed of diffusion of chloride ions through the protective matrix, which is influencing the electro migration process upon salt spray exposure. The speed of migration of chloride ions in dry materials is orders of magnitude slower than in water. Consequently, as illustrated in Figure 2, chloride ions are going to diffuse in polymer materials from water molecule to water molecule. A higher water content in the material will result in more preferential paths for chloride ions and will speed up the migration of ions. If the speed of migration is about three times faster in one material, there will be a need for three times more material to withstand the salt spray exposure, provided that adhesion properties of both materials are similar. If no chemical adhesion is obtained between the substrate and the protective material, the preferential path for chloride ions is likely to be through the interface and the resistance to salt spray will be highly impaired.

**Modes of silicone contamination**

An excellent review about the various mechanisms by which silicone contamination can

occur is contained in the IVF report<sup>[5]</sup>. When discussing silicone contamination, it is necessary to distinguish between fluid and volatile molecules. A volatile molecule is defined as a liquid or a solid molecule that shows a certain degree of volatility, i.e. exhibiting a vapor pressure. Low molecular weight silicones will display a finite vapor pressure, while silicone polymers having a degree of polymerization above 20 can be considered as pure 'non-volatile fluids'. The volatility of silicone materials depends on temperature, molecular weight and molecular structure as illustrated in Figure 3: a linear molecule is less volatile than a cyclic molecule and a small molecule is more volatile than a large molecule. The volatility of silicone molecules increases with temperature, but is limited by the temperature degradation of the molecules. At 20°C, L10 can be considered as a pure fluid, but it will be as volatile at 100°C as D6 at room temperature. Similarly, L10 will be as volatile at 200°C as L3 at room temperature. It is therefore necessary to consider the temperature factor when volatile contamination is involved.

Now that a clear definition of a fluid and a volatile has been established, it is possible to describe the contamination accordingly. There are basically

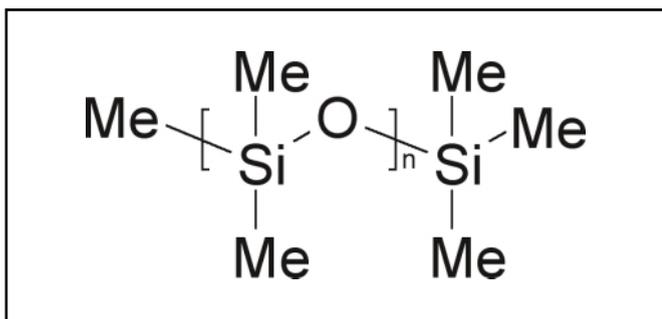


Figure 1. Silicone polymer chemical structure. n+1 is the degree of polymerization.

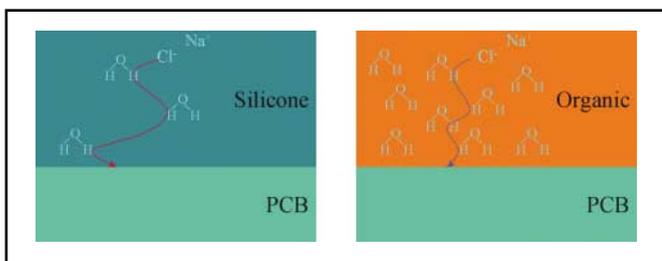


Figure 2. Migration of chloride ions during salt spray exposure.

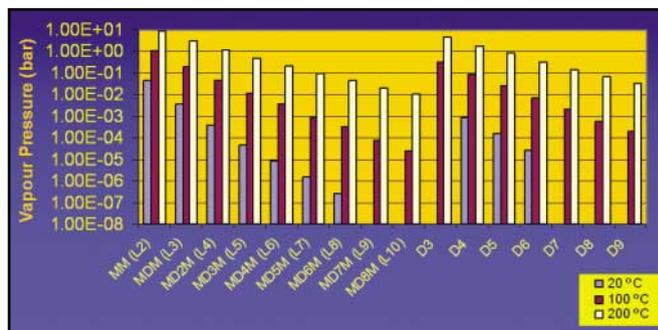


Figure 3. Vapour pressure of various silicone volatiles. L2 to L10 are linear silicone oligomers with degree of polymerization from 2 to 10, while D3 to D9 are cyclic silicones having 2 to 9 monomer units.

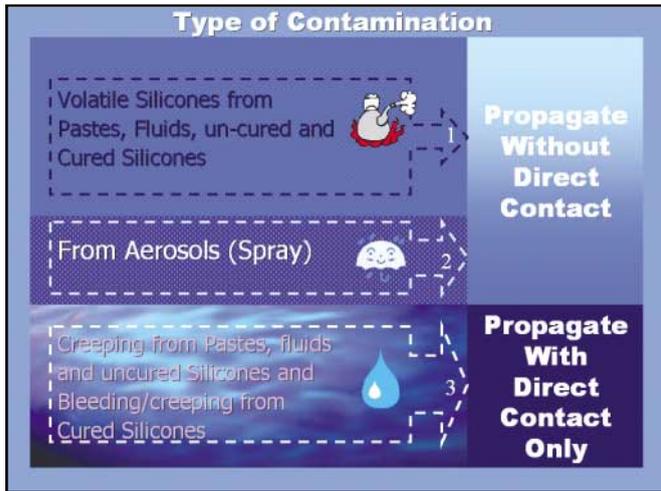


Figure 4. Types of contamination with silicone materials.

three possible cases leading to two separate modes of contamination (Figure 4): contamination can occur with volatile silicones, with silicone aerosols and with silicone fluids.

The mode of contamination with volatile silicones and aerosols is identical: it propagates through the air without direct contact. But the consequences are very different, as aerosols can be made up of non-volatile fluids and hence induce fluid contamination. Since aerosols are not formed during conformal coating applications, we will not consider this mode of contamination at this time. It is widely recommended to avoid the use of spray cans of any sort in coating or soldering production areas as aerosols could end up on sensitive substrates via air conditioning ducts.

Apart from aerosols, fluid contamination can only occur through direct contact and cannot propagate through the air. The key difference between fluid and volatile contamination is that a volatile, unless trapped in a process, will escape very easily, while a fluid will stay there forever - unless removed by the process.

Therefore, silicone volatiles do not represent an issue for soldering or painting processes,

as these compounds will be displaced easily from the surface of the substrate. At room temperature, a silicone volatile such as D5 is completely eliminated from any surface in less than 15 minutes provided it is not within a confined area. Conversely, a surface being contaminated with a fluid is a concern for the soldering or painting processes.

Surprisingly, silicone fluids can be removed from sensitive substrates with the use of silicone volatiles. Silicone volatiles are ideal solvents for uncured silicones and hence represent very effective cleaning agents for silicone fluids. As mentioned above, volatile contamination will only occur if the volatile cannot escape and is trapped by a chemical reaction or in a confined area. Volatile silicones can be an issue for electrical motors, relays, potentiometers where arcing degrades silicone species into siliceous compounds that deposit an insulating abrasive layer on the contacts. This generates either increased contact resistance in relays and potentiometers or failure in electrical motors due to abrasion of the collector<sup>[1-4]</sup>. Another example is headlamps, where silicone volatiles can be degraded by UV and form siliceous

compounds depositing as a white residue on the reflector. This occurrence is known as 'fogging'. It is noteworthy that organic volatiles are also degraded by the same processes, forming a yellow to brown residue on the reflector; this residue is not immediately discernable in relays and potentiometers as it is electrically conductive, but, in extreme cases, its incomplete combustion could lead to fire in the relay.

Fluid contamination could also present a problem for relays, potentiometers and electrical motors if, but only if the fluid comes into direct exposure with the electrical contacts in these parts. If a tight barrier is present, as is the case for sealed relays, there will be no fluid contamination in these parts. However, even in sealed relays and especially with wave-soldered relays, micro-cracks can occur, allowing for the silicone to migrate and create contact resistance.

#### How to avoid fluid contamination with silicones?

The most effective method of preventing fluid contamination is to avoid any direct contact between the silicone and the sensitive substrate. As far as silicone conformal coatings are concerned, the only potential risk stems from direct dispensing onto the sensitive substrate, such as a solder pad, an electrical motor, a potentiometer or a non-sealed relay.

Does this mean that silicone-based conformal coatings are not suitable for boards populated with such sensitive devices? Surprisingly, the answer to this question is no. Actually, silicone conformal coatings are currently used in applications where such sensitive devices are present without any resulting fluid contamination issues.

Naturally, good housekeeping

is required to ensure that no fluid is transferred from one production area to another. An appropriate coating process will make sure that the silicone is dispensed only where needed. A controlled curing process will ensure that silicone is properly cured and that the possible migrations are prevented. It is noteworthy that even a fully cured silicone conformal coating still has a small percentage of uncured fluid that could bleed out of the material and migrate along the surface. The migration process is, however, much slower than with uncured materials. In the IVF report on silicone contamination it is shown that the migration process takes place over several weeks on a gold substrate, which is one of the most sensitive substrates as far as silicone migration is concerned<sup>[5]</sup>.

Therefore, in proximity to solder pads, it is necessary to cure the material quickly to prevent fluid migration and to solder in a reasonable timeframe. Because of the presence of these uncured materials, it is not advisable to bring a cured silicone into contact with a solder bath. Nowadays, recent silicone technologies developed for aerospace applications demonstrates no migration on gold even after 17 weeks<sup>[5]</sup>.

#### How to avoid volatile contamination with silicones?

It must be understood that all silicone-based materials before and after cure have a certain percentage of silicone volatiles. In standard materials, this varies from 0.5 to 3%, but it can be even more in some very low viscosity conformal coatings. Recent technologies have been developed to reduce the amount of silicone volatiles to a very low content; these materials are commonly referred to as controlled volatility (CV) silicones.

Today, easily processable CV conformal coatings exhibit less than 0.001% of silicone volatiles. In electrical motors, potentiometers and relays, it has been demonstrated that there is a threshold below which high contact resistance will not occur<sup>[6]</sup>. This critical level is around 10 ppm of silicone volatiles in the air. Tests have been conducted in order to determine the impact of silicone volatiles in varying concentrations. In both cases, a cured silicone material containing a specific volatile content was enclosed in a confined area with the component. The relay was switched on and off at a 5 Hz frequency cycle, while the electrical motor operated under normal conditions. The results are presented in Figures 5 and 6. These figures show that the latest material technologies allow the application of silicones in close proximity of electrical motors and relays even within confined areas. The threshold was found to be close to 30 ppm of D4 (worst case).

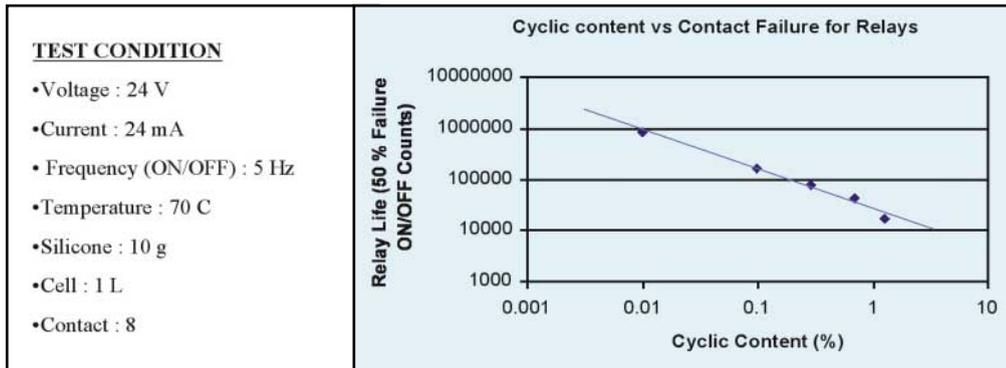


Figure 5. Contact failure for relays enclosed in a confined environment containing a silicone material volatile silicones (D4-D10).

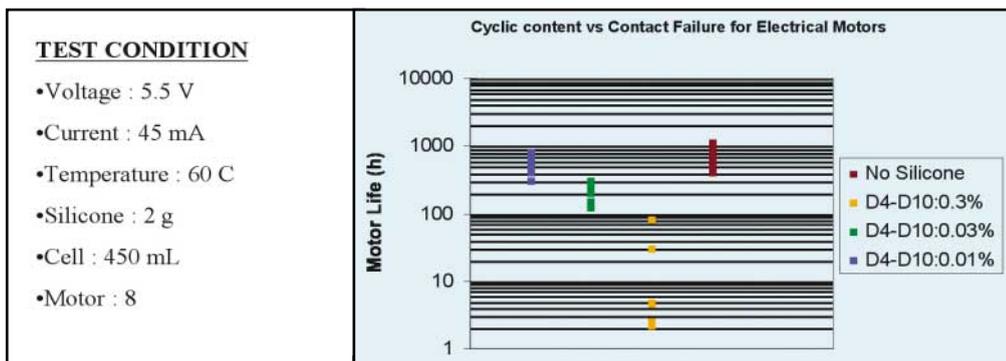


Figure 6. Life of electrical motors enclosed in a confined space containing volatile silicones (D4-D10).

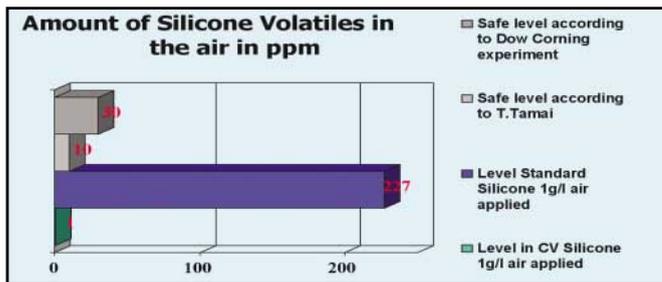


Figure 7a. The amount of silicon volatiles in the air (ppm).

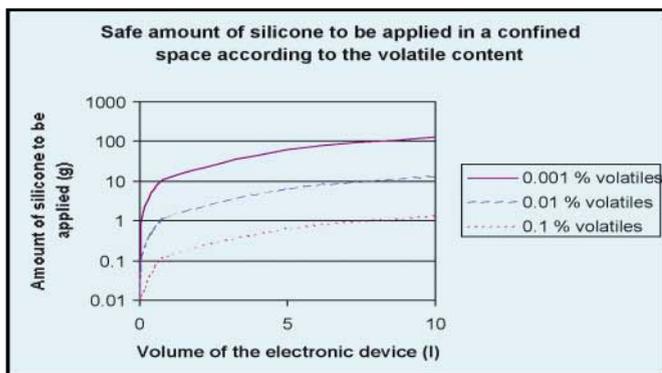
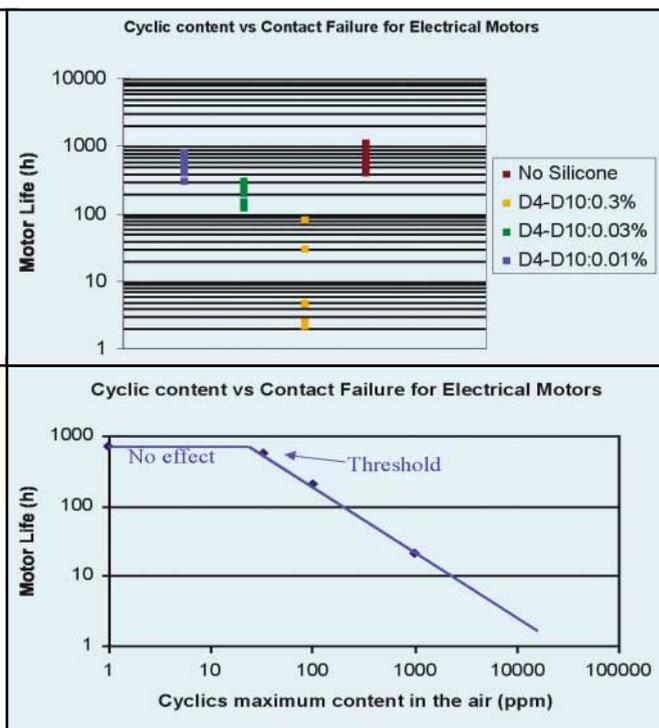


Figure 7a. Safe level of volatiles in the air for electrical motor & relays.



The graph at Figure 7a illustrates well the difference between a standard silicone and a CV silicone. Applying 1 gram of a standard silicone in a confined 1-liter space is going to seriously harm any electrical motor and any relay, while 1 g of a CV silicone will be totally harmless. This is reinforced by the graph in Figure 7b, which plots the maximum amount of silicone that can be applied in proximity to sensitive components within a hermetically enclosed housing. These data are displayed as a function of the volume of the unit and the amount of

volatile that is present after cure. Is it possible to apply a standard silicone in close proximity to relays and electrical motors? Yes. There are many existing applications where standard silicones are used, but the electronic devices should be exposed to the air in order to allow the silicone volatiles to escape.

**Conclusions**

Recently developed silicone technologies (e.g. controlled volatility) demonstrate a proven record of performance in close proximity to sensitive devices, such as relays, electrical motors,

potentiometers, optical devices and solder pads. In some cases, controlled volatility materials can be applied safely even in very confined environments.

Today, the risks are well known and very much reduced by recent process techniques and materials technologies. In case of doubt, analytical methods are available to quantify and control any element of the risk.

In full support of current US legislations and emerging EU legislations relative to VOC emissions and the need to ensure reliable electronics, especially in the automotive sector, the use of silicone conformal coatings is likely to increase in future years.

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