



The Use of Silicone Materials in Close Proximity of Electrical Motors and Mechanical Relays

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It is surprising to see that the commercial launch of silicone-based materials dates back to 1943, and that the first article dealing with silicone contamination of electrical motors was actually published in 1944(1)! In the following years, more publications were issued on that topic (2,3). The following sentence from L.E. Moberly(4) 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. However, who could guess that this was written in 1960? These articles were published,

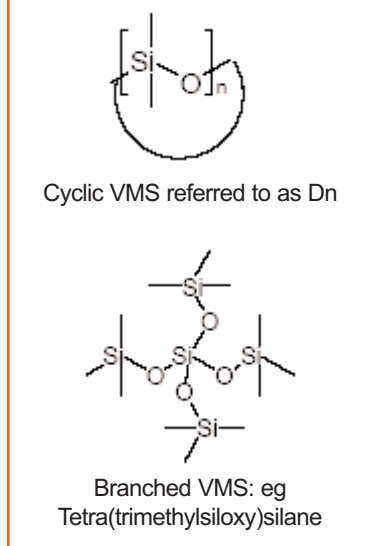


Figure 1: Types of volatile methyl siloxanes (VMS)

years before silicone contamination issues were happening with relays in the telecommunication industry and years before silicone contamination in 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". Because contamination of electrical motors and relays are occurring most of the time through volatile contamination, the present article will principally deal with this mode of silicone contamination and its prevention. Today, there are multiple ways to resolve these issues and recent developments have addressed both volatile and fluid contamination (8).

Mode of Contamination with Silicone Materials

An excellent review about the various mechanisms by which silicone contamination can occur has been published (5). These mechanisms have been further investigated elsewhere (6-8). When discussing silicone contamination, it is required to clearly distinguish between fluid and volatile molecules. Part of the confusion around silicone contamination is due to the fact that a fluid is sometimes volatile and sometimes not volatile. In order to clearly separate the two types of contamination, the following discussion will make the distinction between:

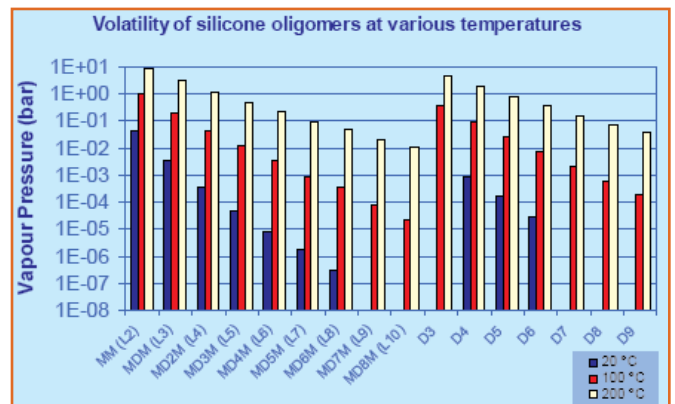


Figure 2: Vapour pressure of various silicone volatiles. L2 to L10 are linear silicone oligomers with degree of polymerization from 2 to 10, while D3 to D9 are cyclic silicones having 2 to 9 monomer units.

- A silicone volatile VMS (volatile methyl siloxane), which up to the degradation temperature of the polymer has a low molecular weight and a measurable amount of molecules in the vapor phase. And

- a silicone fluid, which up to the degradation temperature of the polymer has a very high molecular weight (above 1000) and does not have any molecule in vapor phase.

Therefore, the ambiguity that is implied by the terms "silicone volatile fluid" is excluded in the above-mentioned definition since a volatile fluid is classified as a silicone volatile (VMS). There are three categories of VMS according to its chemical structure as depicted in figure 1, i.e. linear, cyclic and branched VMS.

Low molecular weight silicones - with a low polymerization degree n - will display a finite vapor pressure, while silicone polymers with n above 20 can be considered as pure "non-volatile fluids". The volatility of silicone materials depends on temperature, molecular weight and molecular structure as illus-

trated in figure 2: 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 of degradation of the molecules. At 20°C, L10 - having 10 silicon atoms in the chain - 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 required to consider the temperature factor when volatile contamination is concerned.

Types of Contamination

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 3 possible cases leading to two separate modes of contamination (figure 3): 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. It is widely recommended to avoid the formation of aerosols or 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, mostly chemical, will escape very easily. A fluid will stay on a substrate forever, unless removed by the process. Volatile silicones can be an issue for electrical motors, relays, potentiometers where arcing degrades silicone species into siliceous compounds that deposit as an insulating abrasive layer on the contacts. This layer generates either contact resistance increase in relays and

potentiometers or failure in electrical motors due to abrasion of the collector (1-4). If arcing is prevented volatile then silicones will not be degraded. In that case they will not represent any issue for the component. For instance, it is well known that volatile silicones are harmless for brushless electrical motors.

Fluid contamination could also represent a problem for relays, potentiometers and electrical motors if and 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, especially with wave-soldered relays, micro-cracks can occur, allowing for the silicone to migrate even more easily with increased capillary forces and create contact resistance. Actually, fluid contamination of relays and electrical motors is easily detectable and is leading to faster contact resistance than volatile contamination. The remedy is to create a nonsurmountable barrier to the fluids.

How to Avoid Volatile Contamination with Silicones in Electrical Motors and Relays

It must be pointed out that all silicone-based materials before and after cure have a certain percentage of silicone volatiles. In

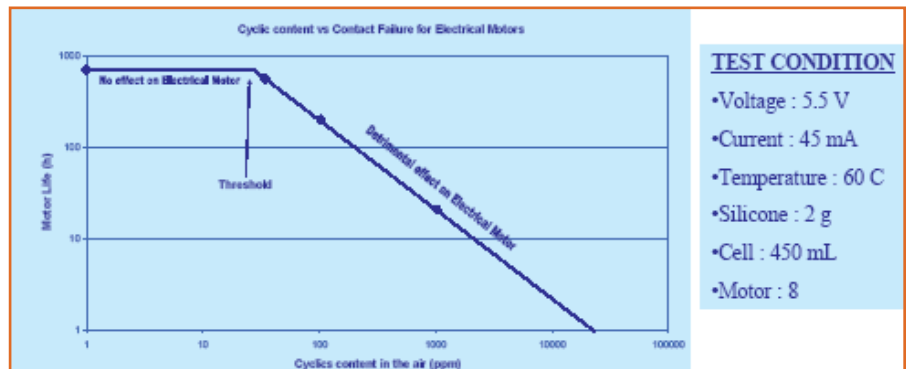


Figure 4: Life of electrical motors enclosed in a confined space containing volatile silicones (D4-D10). The cyclic content in the air is the maximum content that is coming out of the 2 g of silicone.

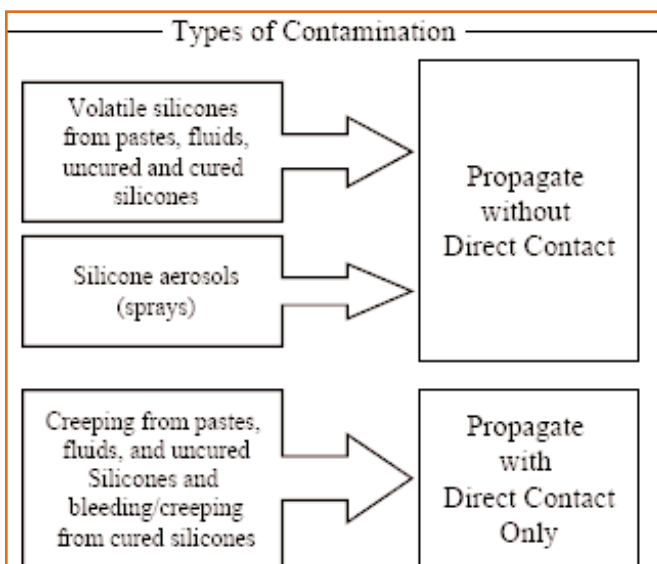


Figure 3: Types of contamination with silicone materials

standard materials, this varies from 0.5 to 3 percent, 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 percent of silicone volatiles.

It has been demonstrated that there is a threshold in the ambient air below, which the formation of the siliceous layer will not form in electrical motors, potentiometers and relays (8,9). This critical level is around 10 to 30 ppm of silicone volatiles in the air and has been discussed in details elsewhere (9). Figure 4 is showing that in the case studied amounts below 30 ppm of silicone volatiles did not have an impact on the motor life.

The amount of silicone volatiles present in various cured silicone materials has been measured by Gas Chromatography with a Flame Ionization Detector (GCFID) after calibration with standards. The total VMS content obtained is listed in table 1 and show significant differences between the products studied. Indeed controlled volatility materials are containing much less silicone volatile materials than standard products. Generally,

Table 1: Measured content of volatile methyl siloxane (VMS) in various cured silicone materials from Dow Corning Corp. A 2 mm thick sheet has been made and cured accordingly to table 1. A fraction of the cured material has been put in toluene for extraction of the volatile species and then analyzed by GCFID.

Product	Material type	Controlled Volatility Silicone	Curing conditions	VMS content (%)
1-2577	CC	N	72h@RT	1.370
3-1965	CC	N	24h@RT	0.680
1-4105	CC	N	10min@105°C	0.474
HC2000	CC	Y	1.5h@RT	0.002
3-1944	CC/AD	N	24h@RT	0.697
3140	CC/AD	N	72h@RT	1.428
3145	AD	N	48h@RT	1.408
866	AD	N	1.0h@130°C	0.189
7091	AD	N	48h@RT	0.496
3-6265	AD	N	30min@150°C	0.159
Q1-9226	TCAD	N	1.0h@100°C	0.112
Q3-3600	TCENC	N	30min@150°C	0.104
170	ENC	N	24h@RT	0.425
567	ENC	N	1.0h@125°C	0.194
184	ENC	N	45min@150°C	0.277
SE1815CV	ENC	Y	30min@150°C	0.005
SE1816CV	ENC	Y	1.0h@100°C	0.030
SE1819CV	ENC	Y	1.0h@100°C	0.015
527	G	N	24h@RT	0.426
3-4207	G	N	15min@RT	0.982
SE4490CV	TCC	Y	NA	0.017
340	TCC	N	NA	0.088

CC = Conformal Coating
AD = Adhesive
TC = Thermally Conductive
ENC = Encapsulant
G = Gel
TCC = Thermally Conductive Compound

due to their high filler content, thermally conductive materials exhibit a lower VMS content than standard silicones.

It is important to notice that content in linear silicone volatile is very limited. Actually in most products studied the level of these species is not detectable. In the products shown in table 1, only 3-1965 is containing a measurable amount of L3. The biggest part of the VMS content is composed of cyclic molecules. This can be explained by the fact that silicone cyclics are formed naturally by depolymerisation of the polymer. Linear molecules are not formed significantly during this process. They are only present if they are part of the initial formulation of the product.

Illustrating Examples

A tool has been designed in order to calculate the amount of volatile silicones present in the air around the sensitive device, according to the parameters such as temperature, volume, pressure and silicone composition. This tool performs a calculation based on the perfect gas law from the vapor pressure of the volatile species present in the materials after cure. With the help

Product	Material type	Controlled Volatility	Curing conditions	Volatile Methyl Siloxane (VMS) Content after Cure (%)										Total (%)
				D4	D5	D6	D7	D8	D9	D10	D11	D12	L3	
1-2577	CC	N	72h@RT	0.018	0.121	0.258	0.193	0.189	0.161	0.134	0.121	0.176	0.000	1.370
HC2000	CC	Y	1.5h@RT	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002

Table 2: Detailed VMS composition of two conformal coatings for illustrating examples

of this tool, while taking a conservative approach, it is possible to determine whether the use of a certain type of silicone is appropriate or not for a given application. Three example cases have been developed in order to illustrate typical scenarios and values in table 2 have been used for calculation. One basic assumption for this calculation is that the system has reached its equilibrium.

Example Case #1:

The use of Dow Corning 1-2577 Conformal Coating to protect a printed circuit board PCB containing relays or electrical motors.

Hypothesis:

- 1 liter totally hermetically closed device that contains either (a) relay(s) or (an) electrical motor(s). For the sake of simplification all relays (even sealed relays) should be considered as not tightly sealing against VMS. This is a conservative approach, but this assumption enables user of silicone to be sure about proper function of their devices in the application.
- 10 by 10 cm² PCB to be coated with 70 μm thick coating
- Service Temperature of the device –40 to 150°C
- Cure conditions according to table 1
- The bottom of the relay or motor is above the level of silicone, which means that the silicone conformal coating is not sealing the component. If this would be the case, one had to consider the component atmosphere separately.

Calculations:

At –40°C, nothing should happen, as none of the species are volatile, but at 20°C, there will be about 200 ppm of VMS in the device and hence in the component. This is far above the threshold value of 30 ppm. At 150°C, the amount will double, i.e. 400 ppm. In the present case, there is enough VMS in the proximity of the relay and arcing will build a siliceous layer around the relay, which might result in contact resistance. We clearly would recommend the use of a CV silicone in the present case. This will be the purpose of Example case #2, where everything is the same as example case #1, except for the product used.

Example Case #2:

The use of Dow Corning HC2000 Controlled Volatility CV Conformal Coating to protect a printed circuit board PCB containing relays or electrical motors.

Hypothesis:

- 1 liter totally hermetically closed device that contains either (a) relay(s) or (an) electrical motor(s). For the sake of simplification

all relays (even sealed relays should be considered as not tightly sealing against VMS. This is a conservative approach, but this assumption enables user of silicone to be sure about proper function of their devices in the application.

- 10 by 10 cm² PCB to be coated with 70 µm thick coating
- Service Temperature of the device -40 to 150°C
- Cure conditions according to table 1
- The bottom of the relay or motor is above the level of silicone, which means that the silicone conformal coating is not sealing the component. If this would be the case, one had to consider the component atmosphere separately.

Calculations:

At -40°C, again nothing should happen, as none of the species are volatile. At 20°C, the maximum amount of VMS is about 0.46 ppm, which is far below the threshold value of 30 ppm. At 150°C, the amount will raise up to 0.64 ppm, which is also far below the threshold value. The amount of volatiles present is way too low to build a siliceous layer on the contacts and there will be no impact on the functioning of the relay. We are confident that there will be no issue with this product in this application. Now does it mean that 1-2577 can never be used in close proximity of relays or electrical motors? Actually in some cases it can be used, we will focus on this particular case in example case # 3, describing a system similar to example case #1, but where the device is opened to the air.

Example Case #3:

The use of Dow Corning 1-2577 Conformal Coating to protect a printed circuit board PCB containing relays or electrical motors.

Hypothesis:

• 1 liter totally open device that contains either (a) relay(s) or (an) electrical motor(s). For the sake of simplification all relays (even sealed relays) should be considered as tightly sealing against VMS. This is a conservative approach, but this assumption enables user of silicone to be sure about proper function of their devices in the application.

- 10 by 10 cm² PCB to be coated with 70 µm thick coating
- Service Temperature of the device -40 to 150°C
- Cure conditions according to table 1
- The bottom of the relay or motor is above the level of silicone, which means that the silicone conformal coating is not sealing the component. If this would be the case, one had to consider the component atmosphere separately.

Calculations:

Basically the calculation would lead to the same figures as example case #1. However, the present assumption is considering an open-to-the-air box. The kinetic theory of gases predicts here that all silicone volatiles present in the air will be escaping through a hole of 1 mm² in less than 1 day. This means that the level of VMS in the air will never reach the threshold value, because the volatile species can easily escape. It is therefore possible to apply a standard silicone in proximity to relays and electrical motors. There are many existing applications using standard silicones to protect PCBs that are either containing relays or electrical motors without any trouble for this reason. Actually, the sensitive cases are the ones where the electronic device is sealed and therefore hermetically close to prevent water ingress. In such a

case, the use of a CV silicone is recommended.

In any case, we strongly recommend the reader that would like to design such a unit to contact us for assistance. We will not take responsibility for any misuse of the content of this article. To be complete, it must be noted that other ways to prevent contact resistance have been published (10). This alternative technology is preventing the formation of the siliceous layer around the contact.

Conclusions

Recently developed silicone technologies (e.g. controlled volatility) allow the use of silicone in close proximity to sensitive devices, such as relays, electrical motors, or potentiometers. In some cases, controlled volatility materials can be applied safely even in very confined environments. In some cases standard silicone materials can even be used. 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.

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