

FIGURE 19.9

A comparison for particle size effect for SiO₂ contamination at the same concentration level.

effects of mineral particles on resistance are more severe and higher currents are less effective in reducing the effects.

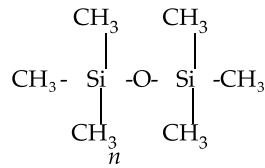
In summary, the effects of mineral particulate contamination on contact resistance are mainly seen in the initial portion of the contact life. The severity of the effects will vary as a function of switching current and voltage and also concentration and particle size of the mineral. In many cases the particles are embedded or partially embedded in the surface and do not produce elevated resistance reading until some arcing takes place on the contact surface.

19.4 Silicone Contamination of Arcing Contacts

One of the most troublesome types of contaminants for arcing contacts consists of silicone compounds. Chapter 10 introduced a brief discussion of this phenomenon. Many types of silicones have been developed for numerous applications including lubricating oils, mold release agents, potting materials, plastics components, rubber seals, sprays for insulation, lens cleaning solutions, and more. As a result of the broad use of these compounds, unintentional exposure of contacts to these materials happens frequently. Silicone contamination is sometimes confused with contamination from mineral forms of the element silicon which were discussed in the previous section. In this section, it will be shown that although silicones may produce mineral materials on the contact surface, as a result of breaking down during arcing, the characteristics of the surface deposits in terms of distribution and concentrations during switching life are quite different from what is seen owing to direct contamination from mineral particles. Silicone contamination normally produces no adverse effects early in switching life, but later can cause catastrophic resistance failures, while direct mineral contamination is usually worst early in switching life and becomes less of a problem in later life.

As a result of its physical characteristics, silicones can contaminate contacts by vapor deposition, surface migration, and combinations of surface and vapor transport. Work published on this subject has emphasized either the vapor-deposition mechanism [52–58] or the surface migration [49,59,60].

Common silicone fluids are dimethyl silicones, which have the following typical structure, where n is the degree of polymerization:



A typical silicone product is composed of a mixture of molecules having a broad molecular weight distribution. Some of the attributes of silicones that make it good for use as a lubricant are the stability of silicones over a wide temperature range and their low surface tensions, 17–22 dynes cm^{-1} [59] which allows good wetting of surfaces. These same attributes which make silicones good as a lubricant are harmful for applications using arcing contacts, since silicones will wet and spread, migrate, over nearly all types of materials. The molecular weight distribution of a silicone product will have an effect on the rate and ability for the silicones to spread. Lower molecular weight fractions of silicone have lower viscosity, which gives them faster surface migration rates than higher molecular weight fractions of silicone [59]. With regard to vapor transport, the vapor pressure of silicone exponentially becomes larger as the molecular weight decreases, and for low molecular fractions, evaporation takes place even at room temperature [54]. The low molecular weight fractions of silicones are clearly the most troublesome types of silicone contamination for contacts.

Although silicone transfer normally involves both vapor and migration the discussion will be divided into two sections: one where vapor transport is the main mechanism and the other where migration is the main factor for transport and contamination. In following this discussion, it should be kept in mind that factors connected with an electrical switching application such as electrical load type, current level, voltage, contact force, erosion rate, and switching rate can have a large effect on a specific result.

19.4.1 Contamination from Silicone Vapors

The work done on silicone contamination by vapor phase will be discussed first. This process can be considered very similar to the processes discussed in Section 19.2 on contact activation by organic vapors. The organic vapor activation process was mainly concerned with switching at low currents, less than 1 A. and the effects of activation on contact erosion more than the effects of contact resistance. For silicones, concerns are mainly with the effects of contact resistance. The effects also extend to much higher current ranges compared to resistance associated with organic activation. Automotive relays operating at 20 A or more have been found to fail as a result of silicone vapor and migration contamination [61]. The effects of silicone vapors on arcing contacts do not appear immediately on exposure to the silicone but normally after hundreds or thousands of switching operations, similar in timing to organic vapor activation.

Tamai studied the effects on contact resistance from decomposition of silicone vapor onto a heated gold surface [55]. He found that the decomposition and formation of silicon dioxide began at about 300°C and that films of sufficient thickness to cause high resistance readings for 10 cN of contact force started above 600°C. This work also showed that the decomposition at these temperatures left no carbon residue and that the amorphous glass deposits were stoichiometric silicon dioxide, SiO_2 . Figure 19.10 shows the relationship of the contact resistance to the thickness of the silicon dioxide that was formed on the gold contact and indicates a sharp increase in resistance as the thickness approaches 1000 Å [0.1 μm] [54]. The contact forces utilized in this work were relatively low compared

to forces used in typical arcing devices, but the results indicate that SiO_2 films thicker than 1000 \AA will cause resistance problems even for devices having higher contact forces.

The effects of silicone vapors on arcing contacts will depend on many interrelated factors including vapor concentration, operating temperature, frequency of switching, type of silicone and more. The relationship of molecular weight in terms of degree of polymerization and temperature on vapor pressure of silicones is shown in Figure 19.11 [55]. It can be seen that silicones with degrees of polymerization less than 8 have vapor pressures of 10 p.p.m. or more at room temperature. For applications at elevated temperatures such as automotive relays, 125°C , the degree of polymerization must be greater than 12 to keep vapor pressures less than 10 p.p.m. The reason that 10 p.p.m. is used for this illustration is that the authors, on the basis of work they had performed, thought that below this level resistance failures would not occur. However, later work showed that this is not true [56,57].

From the published work on silicone vapor contamination, the effect of switching rate (operations per unit time) on failures from resistance may not seem clear. Ishino and Mitani [50] showed, for testing enclosed relays with silicone sleeves at 24 V dc and about 0.1–0.2 A, failures at 1000 operations for a switching rate of two operations per hour and failures at 150,000 operations for a switching rate of 30 operations per minute. Eskes and Groenendijk testing under similar electrical loads found that the number of operations to failure was independent of switching rate for the rate range of seven operations per second to only a few operations an hour [53]. This work was done in an artificial environment controlled at a rather high silicone concentration of 500 p.p.m. Tamai and Aramata tested relays at a single relatively fast switching rate of 10 operations per second under silicone concentrations from 0.1 to 300 p.p.m. and found that the time to failure was inversely proportional to the silicone concentration except for the low concentrations, for which no failure occurred even after prolonged life testing [55].

For the above three examples, using some of the same criteria discussed in Section 19.2 for organic vapor activation, an explanation can be made to fit each case as follows:

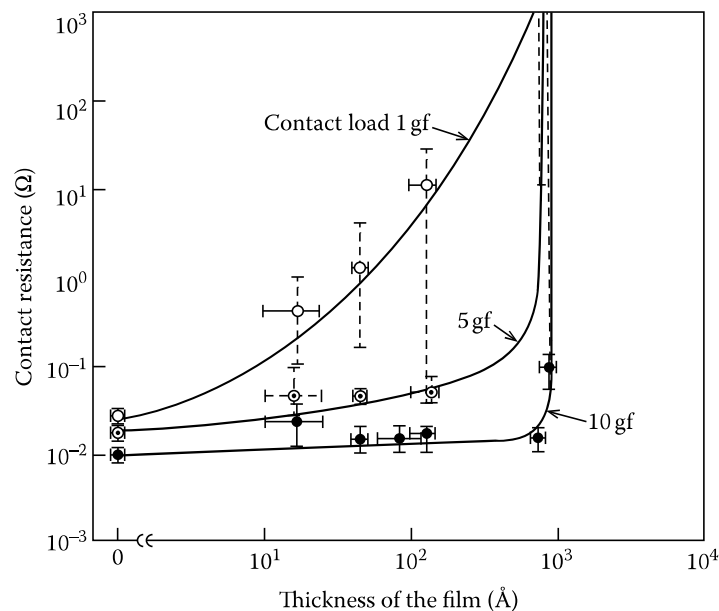


FIGURE 19.10

Contact resistance as a function of SiO_2 thickness.

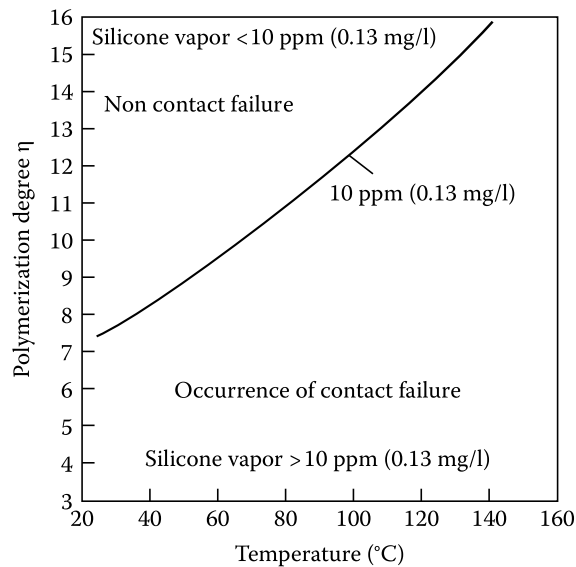


FIGURE 19.11

Relationship of temperature, vapor pressure, and degree of polymerization.

1. The values of the silicone vapor exposure, η , used in the work by Ishino and Mitani were in a diffusion-limited range for silicone adsorption, therefore increasing opening time increased the amount of SiO_2 generated per operation [52].
2. The silicone vapor concentration used by Eskes and Groenendijk in their work was very high and possibly the silicone exposures, η , they used were above the diffusion-limited range. Recall from Section 19.2.3 that the adsorption site limited range is independent of exposure. This would explain why no dependence on switching rate was found for this work [53].
3. The work by Tamai and Aramata for silicone vapor concentrations less than 10 p.p.m. was done at a very fast switching rate which greatly limited diffusion of silicone vapors onto the contact surface between switching operations and prevented a build-up of SiO_2 . Later work by Tamai for the same concentration but at a slower switching rate of 1 Hz versus the previous 10 Hz, resulted in failures for concentrations at 7 p.p.m. and indicated that the former results were limited by diffusion time [56,57].

As mentioned earlier, the low molecular weight silicones are the most problematic. A method of predicting the presence of these harmful weight fractions is to heat the material and measure the weight loss. Eskes and Groenendijk measured the weight loss for a number of silicone materials after heating them at 175°C for 24 hours and found that resistance problems in general increased as the weight loss became greater than 0.3% [53]. Care must be taken to condition the silicone before testing to remove adsorbed water vapor by holding the silicone material at a low relative humidity for 24 hours. Removal of the lower molecular weight fractions of silicones heating the silicone components of a device at elevated temperatures before assembly into the device was shown by Ishino and Mitani to reduce the effects from silicones [52].

Another way for lessening the effects for vapor deposition of silicones is by ventilation. Ishino and Mitani did their work on an enclosed relay with a silicone sleeve. When they

removed the plastic relay cover the resistance problems disappeared. Similar results were reported by Eskes and Groenendijk [53].

For the above-cited papers, the switching currents and energy levels were relatively low compared to typical arcing contact applications. Eskes and Groenendijk show a lesser number of operations is needed for failure as current is increased from 5 mA to 500 mA. Tamai predicts a boundary line of 1.6 W below which no failures occur and above which failures occurred earlier in life as the current was increased to their highest test current, 2 A [56,57]. For organic vapor contamination, Germer found that 100 ergs of energy was near optimum for producing a rapid buildup of carbon [7]. For silicone vapor deposits one would also expect an optimum energy level for SiO₂ build up. As current increases the electrical erosion will play a bigger role, lessening the SiO₂ build up.

Tamai also showed silicone resistance failures for circuit conditions where he suspected that no arcing would have taken place [0.6 A, and less than 4 V] [57]. Here the heating level could result from the molten bridge temperature of the contact alloy, which is more than sufficient to crack silicones. It could also result from the residual temperature of the arc roots on the contact surface. As seen in Section 9.5.4 there is a finite probability that a very short duration arc can form between opening contacts at currents even below 0.6 A. Tamai et al. [62] also did a study of a contact surface exposed to a D4 silicone, siloxane group, vapor environment. This work shows some interesting decomposition mechanisms not discussed before. The D4 exists as both a ring and a chain structure, 0.015–0.085 (ring/chain) equilibrium ratio, see Figure 19.12. A saturation film thickness of one monolayer was formed, 1 nm, in 1–100 hours with the time depending on the vapor concentration. A second layer can also form as a chain structure in the liquid state. For this material a reaction with oxygen in the air over time results in decomposition of the polymer room temperature into a vulcanized structure with higher oxygen content (See also Section 10.6.3).

This study included electrical testing at different currents and voltages using a small relay with less than 10 cN contact force and a resistive dc load. A resistance failure border was found at a switching power level of 1.6W below which failure rates were lower and less severe, see Figure 19.13. The contact surface for failed contacts had deposits of both silica and carbon.

Silicone such as other hydrocarbons will break down and form carbon as discussed in earlier parts of this chapter. In this case, a problem exists for interpretation of carbon

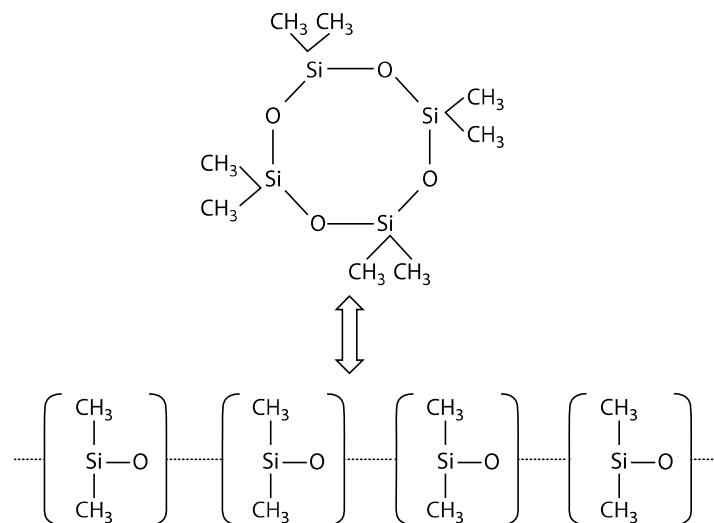


FIGURE 19.12

Silicone D4 which exists as both a ring and a chain structure.

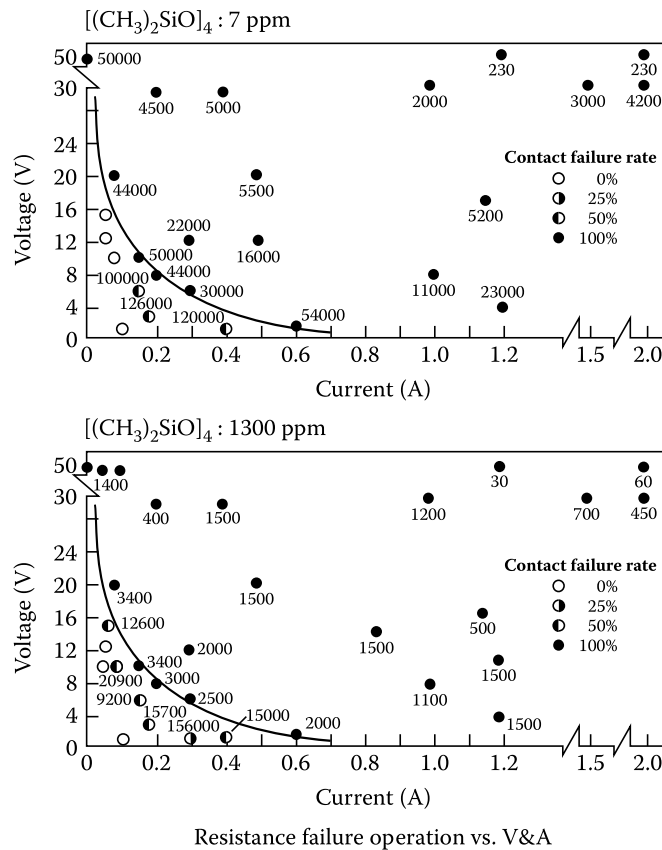


FIGURE 19.13

Results of electrical testing showing a border for contact failure at 1.6 W.

versus silicone resistance failures. As seen in previous sections of this chapter, carbon build up alone can result in high resistance readings. For voltages 15 volts and above silica will easily form from the silicone. At the lower voltages the silica may still form from the added oxygen from the decomposition of the D4, but the high carbon build up at that power level may be the dominant cause for the high resistance in this range of voltage and current. This work clearly shows that in the low power range both silica and carbon are present from the decomposition of silicones.

From the above it can be seen that silicone vapors can cause device resistance problems over a wide range of electrical loads and for very low vapor concentrations. It also can be seen that the silicone vapor exposures follow some of the same rules developed from the long term work done by Bell Labs on carbon activation.

19.4.2 Contamination from Silicone Migration

The contamination of contacts through silicone surface migration is less restrictive than by vapor phase deposition since the contacts don't have to be encapsulated.

As stated earlier, silicones wet nearly all surfaces and will spread over the surfaces at a rate dependent on several factors including temperature, surface roughness, and silicone viscosity [59]. Similar to the case for silicone vapors, the low molecular weight fractions of silicone materials are most problematic since they have lower viscosity and will spread on surfaces ahead of higher-viscosity fractions of the same material. The rate at which the silicone spreads was shown by Kitchen and Russell to be related to the reciprocal of the

viscosity [59]. They found that solid silicone materials such as rubber and sealants with uncured extractable fluid fractions caused problems when the extractable portions were more than a few percent of the total weight and were low in viscosity. They considered compounds with extractable portions having viscosity greater than 1000 centistokes, cSt, relatively safe if the extractable portion is not too high, for example 2.8% at 1200 cSt is relatively safe, 14% at 1030 cSt is marginal, 19% at 24 cSt is high risk [59]. For low viscosity silicones in the 20 to 50 cSt range examples have been found for the silicones to travel over wires easily to devices located several inches away and in one case items several feet away [59].

Witter and Leiper studied the effect of varying the switching rate on the failure rate for contacts coated with a very thin film of silicone lubricant [60]. A 350 cSt lubricant was applied by putting a small amount of silicone oil on a board near the contact and allowing the lubricant to migrate onto the contact surface. The thickness of the silicone film covering the contact surface by this method was found to be about 1000 Å. For this study switching was done at room temperature in open air at 0.5 A and 120 V in an experimental switching device using relatively high contact force, 1.2 N. The switching rate was varied with contact open times from 2.3 s to 960 s. The results for the resistance levels after only 200 operations are given in Figure 19.14. In this case switching rates with contact open times of less than 30 s produced no increase in resistance and those with 60 s or more open time resulted in creating high resistance.

Figure 19.15 is an SEM photomicrograph from a later study by Witter and Leiper [49] showing a contact surface after only 50 switching operations, again at 0.5 A and with 180 s between switching operations. The appearance of high resistance is for a relatively short switching life compared to most of the results cited for vapor-deposited silicone. The thickness of the glassy silicon-rich deposits are much greater than the 1000 Å deposits described by Tamai and Aramata [55] for silica from heated silicone-vapor deposits, and this explains why the resistance remains high even at high contact pressures.

The results show a switching rate dependence for silicone migration, similar to the findings for silicone-vapor depositions in the diffusion-limited exposure range. The mechanism for this build-up is termed "arc-driven migration" [49]. An explanation of this process and the surface chemistry distribution that would be seen as a result of this process is described as follows. Silica, SiO_2 , will be used to describe the glassy silicon-rich deposits

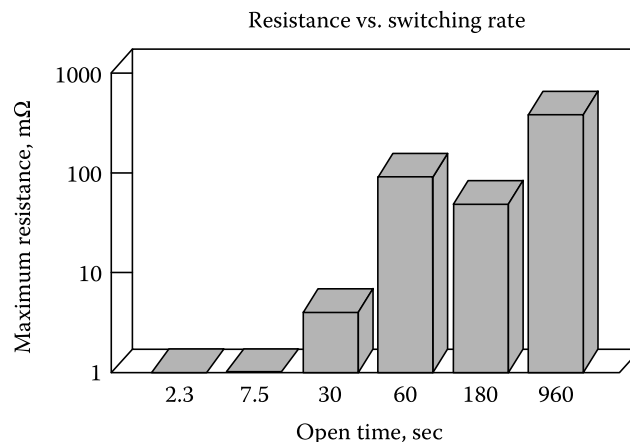


FIGURE 19.14

Resistance as a function of time between switching operations for contacts covered with a thin film of silicone lubricant and switched for 200 operations at 0.5 Å.

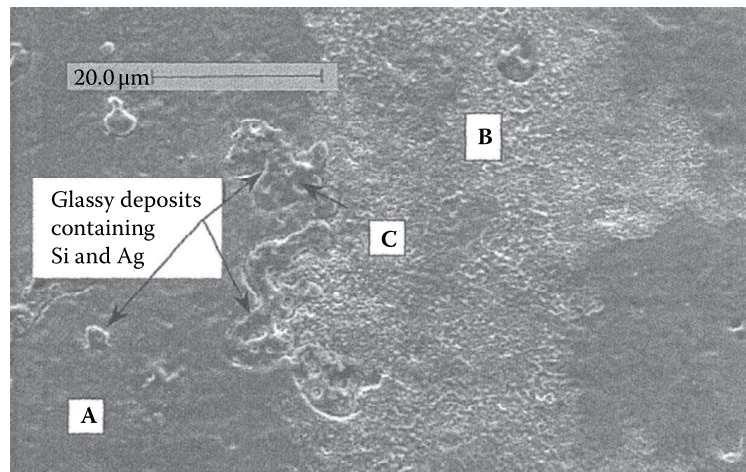


FIGURE 19.15

Arced area after 50 operations showing silicone glass deposits near edge of arced area. (From Rieder W. and Strof T., *IEEE Trans CHMT*, 15(2), 166–171, 1992.)

created by the reaction of the arc and the silicone, although these amorphous deposits may be a more complex glass or just a mixture of silica and silver.

- If a silicone fluid source is near a contact and has a surface path connecting to the contact, the silicone material will, given the time needed, migrate to the contact and cover the entire contact surface as a coating relatively uniform in thickness. The coatings are normally too thin, 1000 Å in the above examples, to be detected by conventional SEM and ED AX and thicker than what would be expected for vapor deposits. Before switching duty these coatings do not cause any contact resistance problems since metal-to-metal contact is made through the film.
- During a single switching operation the silicone film directly in and near the area of the arc is dissociated into silicone glass compounds that are deposited around the arced area. Since low-molecular silicones evaporate in the range of 200°C an area larger than the arc spot would have silicone removed by both evaporation and dissociation. The outer portions of the heat-affected area will have silica deposits from the arc reaction but the silicone film will be removed. The void or film thickness gradient in the silicone created by the arc is the driving force for the silicone material to migrate back into the hole. The migration begins immediately after the void in the film is created.
- The time between successive switching operations is an important factor. For example if the next operation is done immediately there will be insufficient time for silicone to be re-established in the void area and if the arc occurs in the same area there will be little or no silicon glass generated. After this operation as a result of electrical erosion the surface may become cleaner with regard to the glass deposits than it was after the first switching operation. On the other hand, if there is a long delay between switching operations, there will be sufficient time for the void to be filled and a second arc in this same region will again remove the silicone and deposit more silica. A sequence of successive arcing operations under these conditions will, in effect, cause silicone material to be drawn into the arced region and be converted to a build-up of silica, thus the “arc driven migration process.”

Figure 19.16 shows EDXA spectra taken from different regions of Figure 19.15. These results for silicon chemistry spatial distributions are also typical of what is seen in field service failures as a result of silicone migration. Spectrum (a) is for an area of the contact away from the arced area, no silicon line is present since the silicone film is too thin in this area to be detected. Spectrum (b) gives the surface composition average for the entire arced area, after 50 operations, and shows silicon to be clearly detectable and built up compared to the non-arc'd area. Spectrum (c) gives the composition of the large glass deposit in the arced area: both the silver and silicon lines are strong, with only a minor amount of carbon present. From this analysis it is not known if this amorphous deposit is a mixture of silica and silver or a complex glass containing silver and silicon. This point is not so important since the glass deposit is very resistive in either case. The important characteristics of this analysis is the spatial distribution of silicon. If silicon is present only in the arced area as thick glassy deposits, this is indicative of silicone migration.

Kitchen and Russell generated data for silicones of different viscosity spreading over a phosphor bronze substrate [59]. They presented the following equation for approximating the spreading rate of silicones from knowing the spreading coefficient of the lubricant, σ :

$$\Delta A = \sigma t^{1/2} \quad (19.1)$$

Where ΔA is the incremental increase in area, cm^2 , σ is the spreading rate coefficient, $\text{cm}^2 \text{h}^{-1/2}$ and t is the time in hours. The following equation was developed for relating the spreading coefficient of different silicones to their viscosity by using the data that Kitchen and Russell had generated for phosphor-bronze substrates.

$$\ln \sigma = 0.65 \ln(1000/v) + 3.22 \quad (19.2)$$

In this equation v is the viscosity of the silicone in centistokes, cSt.

Using Equations 19.1 and 19.2 the estimated times for silicones to cover different diameter circular areas is plotted in Figure 19.17. It must be kept in mind that the calculations are not exact since factors such as surface roughness, wetting characteristics of the metal silicone combination, temperature, and others can change the results.

The plots in Figure 19.17 can be used to estimate the contact open time needed between switching operations to allow a maximum build-up of silica on the contacts. For example, in the above described work by Witter and Leiper for switching contacts at 0.5 A with

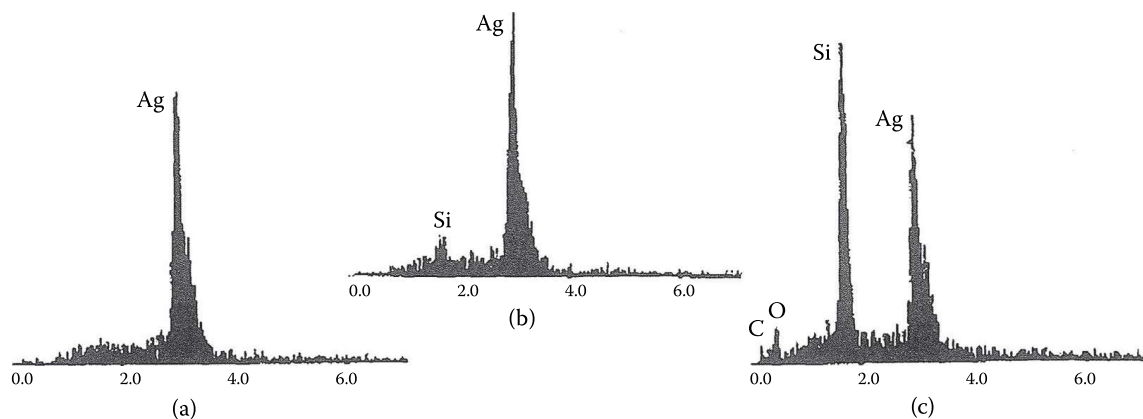
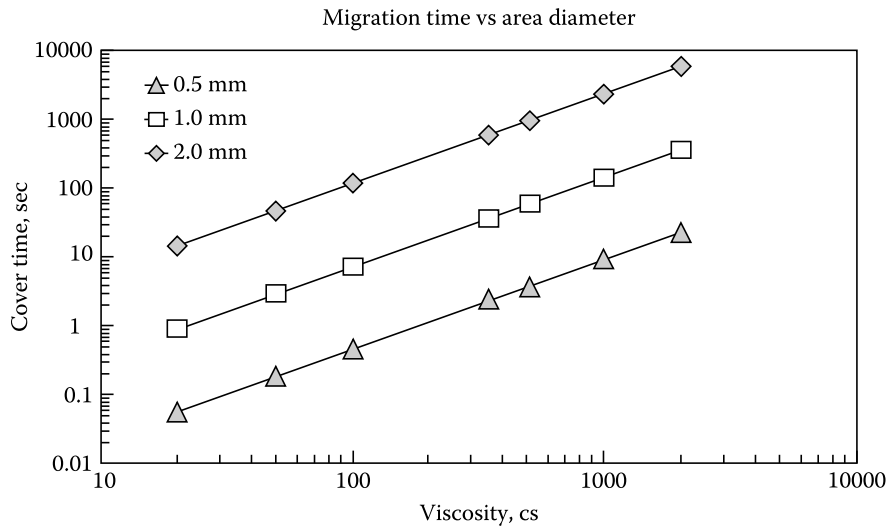


FIGURE 19.16
EDXA spectra for areas A, B, and spot C in Figure 19.15.

**FIGURE 19.17**

Estimated time required for silicone migration to cover different diameter areas as a function of silicone viscosity.

a 350 cSt silicone compound on the surface, the results in Figure 19.12 show that an open time of greater than 30 s, close to 60 s, is needed to generate a large build-up of silica. For this case the arc spot for the 0.5 A load would be about 0.5 mm in diameter. It is known that the silicone depleted area having been affected by a heat of 200°C or more was greater in size than the arc spot. For this example the size was estimated to be twice as large or 1 mm in diameter. Using Figure 19.15 the time estimate for refilling the hole is 35 s, which is lower but in the ball park for 60 s found from the experimental work.

There has been very little published on the effect of current on the results for silicone migration. For example, as the current increases from a level of 2 A to a much higher level such as 50 A, the erosion rate increases by a factor of 2 magnitudes. Cases have been cited where silicone contamination has caused problems for relays operating inrush currents in the 50–100 A range [61]. In such cases, depending on the contact material and the electro-mechanical device characteristics, the electrical erosion can be quite variant, and as a result of this effects from silicone migration may vary. For example, in one case a relay which was designed to operate with silver copper contact material showed no effect from silicone contamination while operating at 50 A, since the surface of the contact eroded away very rapidly. For the same high current load a relay with silver metal oxide contacts that operated with less than one third of the erosion rate failed after 50,000 operations from overheating owing to silica build-up on the contact surface. Further tests conducted on both relays for operating at 12 A with several minutes open time between operations produced failures on both relays in just a few thousand operations. This example shows that qualification testing for devices should include lower current testing with ample time between operations if silicones are at all suspected as a risk. Standard accelerated testing is normally not adequate for detecting problems from silicones since these tests use higher than normal operating current levels, which results in heavier than normal erosion, and also switching rates are too fast to allow replenishment of silicones to the arc spot by migration.

One method that has been recommended for prevention of failures by silicone migration is to coat the area around the contact with a substance with lower surface energy than silicone that will impede silicone migration. Bennett and Zisman found that poly-IH

IH-pentadecafluoro-octyl methacrylate, a polymer that can be put on substrates as a very thin film, was effective for impeding silicone migration [63]. Figure 19.18 shows a comparison of relays tested with exposure to silicone migration with and without the above polymer as a barrier to migration [61]. The silicone source was a silicone rubber seal with a high amount of extractable low-viscosity silicone fluid. The seal was put outside the relay and the barrier was coated onto all the plastic surfaces and terminals. The same relays tested with no silicone exposure are included as a control for comparison. The control results are shown slightly off set with regard to the vertical axis for clarity purposes. The results show the control relay to much better than either test relay. It can be seen that the barrier produces some improvements, but is far from being completely effective in stopping the migration of the silicone. This testing was done at 25°C, and certainly the barrier would be much less effective for testing at higher temperatures where vapor transport of silicone would become more of a factor.

As a result of work done investigating the cause of a high percentage of electrical failures in an automotive line, Witter [64] conducted research comparing both resistive and inductive loads for failure potential as a result of silicone migration. In a study of the failures in the actual cars it was found that the wiring harnesses were contaminated with silicone film and each harness housed about 20 automotive relays. The actual failure reports from the service dealerships showed that failures only occurred for the relays running high inductive loads and no failures were reported for resistive loads or mild inductive loads. All the relays had about the same level of contamination. To verify the findings similar tests were run in the laboratory comparing the two types of loads. Figure 19.19 shows the results comparing two inductive and two resistive loads. The testing was done with an open time of 360 seconds between operations and from 1 to 4 amperes for the inductive loads. The testing on the resistive loads included a range from 3 to 20 amperes and none of the tests showed any changes in electrical resistance as would be expected for contacts exposed to silicone migration.

For resistive and low inductance, automotive loads running at 13 V dc the relays normally interrupt in the metallic state and therefore there is no oxygen to react with the silicone in the arc (see Section 10.3.5). Popular silicones such as the dimethyl silicone shown in Figure 19.4 have too high a ratio of carbon and hydrogen to oxygen to allow the formation of silica without the arc reaching a gaseous state. This explains results seen in this study

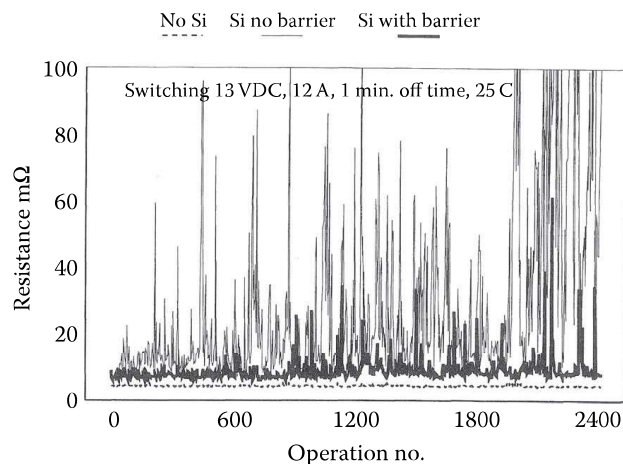


FIGURE 19.18

A comparison of resistance results for relays exposed to external silicone migration both with and without silicone migration barriers.

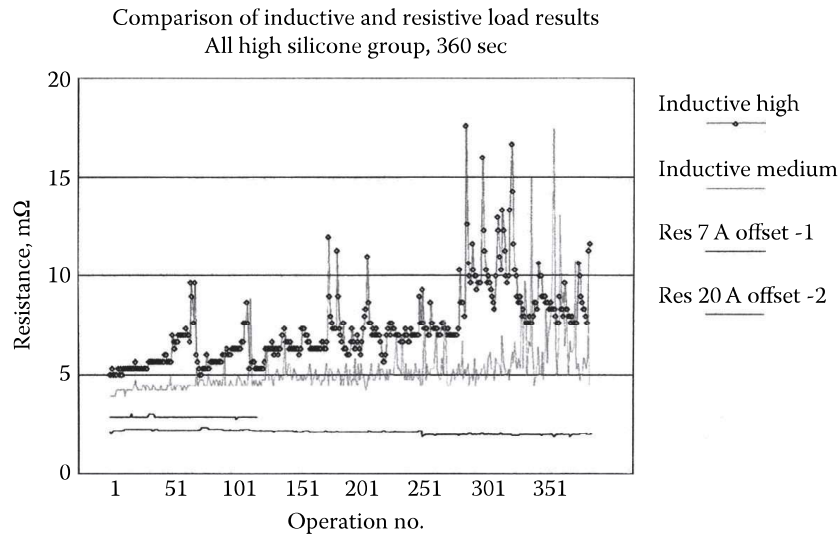


FIGURE 19.19

Comparing the effects of inductive and resistive loads for testing silicone contaminated contacts, bottom lines resistive loads off set and upper plots inductive loads.

where there were thousands of cars involved and a failure rate of 7% for inductive loads and 0% for other loads.

19.4.3 Summary of Silicone Contamination Mechanisms

Silicone contact contamination has been discussed in terms of both vapor transport and migration mechanisms. Actually in all cases both mechanisms will be active to some extent.

In both types of transport, the time between switching operations has an effect on the results. For vapor transport you must have enough time for the adsorption of the silicone vapor to take place unless you have a concentration above the diffusion limited range. In migration you need to provide enough time for silicone to migrate over the arc spot and recover the area that reacted with the arc. Most of the work on studying vapor transport used low currents and low device contact force. For devices using higher forces the results would be much less severe for the same contamination levels. For migration the silicone film can be much thicker than for adsorbed vapors and the resultant silica build up much thicker.

In either case of transport, the detection of silicone films before arc build up is not possible using SEM and EDX analysis and more sensitive surface analysis equipment such as auger and XPS must be used. Once the parts have been exposed to many electrical operations EDX is good for detecting the silica build up.

Different attempts have been made to counteract effects of silicone. The uses of lower surfaced energy coating such as fluorides as described in the previous section are only marginally successful. Another marginal solution is to use contact materials that have a high erosion rate so there is no significant built up of silica. This doesn't work for low current applications. Work by Schrank [65] looked at what had to be done for sealing relays against silicone contamination when put in silicone rich environments. This work showed that water proof seals are not effective and only true hermetic sealing worked. The other solutions being looked at are use of non-silicone type acryl-based polymeric products in the vicinity of the relays, Hasegawa [66], and this is may be the most successful solution.

The following is a summary of points relating to silicone contamination.

1. For silicone vapor contamination the contact must be in an enclosure which contains the silicone source. Silicone vapor contamination is more likely at elevated temperatures but can be a factor at room temperatures where very light molecular weight silicones are present. As the temperature goes up the concentration of the vapor increases but the adsorption amount decreases. Lower concentrations require more time for adsorption.
2. Contamination by silicone migration can take place over long distances and failures can occur for contacts that are not in enclosures. The effects of silicone migration are influenced by the time allowed between switching operations owing to the process described as "arc driven migration." Rapidly switched contact devices may have prolonged life or no failures, while devices that have long time duration between operations may fail rapidly. Migration times for silicone oils are much faster for low-viscosity low-molecular-weight silicones. Migration can produce relatively thick deposits of silicon glass products on the contacts in just hundreds of operations. Even under good contact force these deposits cause high resistance.
3. Qualification testing for electromechanical switching devices is normally done at accelerated switching rates that do not provide enough time between operations to see the effects of silicon migration, they are also normally done at maximum current which increases erosion of the silica, and therefore this type of testing is not effective for screening for silicone contamination. Silicone screening tests should be done with lower currents, inductive loads or voltages at 15 amperes or more, and a long delay between switching operations, 1 to 5 minutes.
4. Effects from silicone contamination do not show up until devices have been in operation for some time and if the contamination of a device is connected with the manufacturing process many parts can be affected before the problem surfaces. This is why screening tests are important.
5. Many different types of silicones have been developed and the decomposition processes can be quite different and involved. They all can cause failures and low molecular weight versions are the most troublesome.
6. Low power weak arcs involve breaking down silicones into both silica and carbon deposits and both contribute to the high resistance.

19.5 Lubricants with Refractory Fillers

Another type of contamination that is often confused with silicones consists of lubricants that contain mineral particles as fillers. The mineral fillers serve as thickeners for increasing the temperature stability of the lubricants. Lubricants of this type are sometimes used with base-metal contacts that have a sliding action for make and break. Little has been published about problems encountered with this type of lubricants for arcing contact applications. Some of the fillers used are silica, alumina, silicates, and magnesium oxide. Klungvedt reported on resistance problems associated with the use of silicate-thickened lubricants used on the contacts of an automotive sliding switch that caused switch overheating and failure [67]. For this application the contact forces are over 1 N and the current