Peroxide or Platinum?
Cure System Considerations
for Silicone Tubing Applications

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Introduction

Silicone tubing has many advantageous physical and chemical properties that have been utilized in medical and pharmaceutical applications for over 40 years. Silicone elastomer, from which tubing is extruded, can be crosslinked and “cured” (or “vulcanized”) into solids by using a variety of cure systems. In health care applications the most commonly used crosslinking chemistries are addition (platinum) and free radical (peroxide) curing systems. This paper will discuss the advantages and disadvantages of both types.

The following are important considerations when choosing among products with different cure systems:

-acceptability of cure system by-products – do they impact drug assay or efficacy?

-product performance – e.g., pump life, burst strength

-appearance differences that could impact visual inspection of fluid contents

Reaction Chemistries

For tubing stocks, source polymers are typically long chains of polydimethylsiloxane, either methyl or hydrogen-substituted, and vinyl-functional polydimethylsiloxane gums. An ADDITION CURE system makes use of vinyl-functional polymers, oligomers with Si-H groups, and a metal complex catalyst, such as platinum (Pt). The reaction is generally as follows (Figure 1):

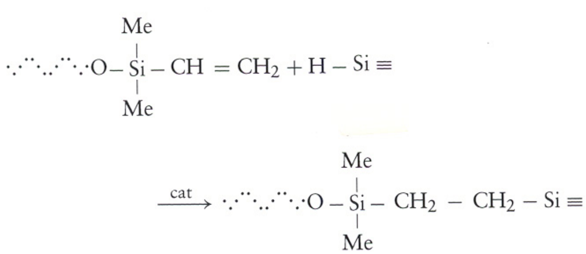


Figure 1. Silicone Crosslinking by Addition

Addition cure has **no** by-products. Platinum in the form of an organometallic complex is used to catalyze Dow Corning® Pharma tubings, although older chemistries utilize platinum salts. Typically 5-15 ppm of Pt is effective for catalysis. Catalyst costs are higher than for peroxide cure systems, which may be reflected in product prices.

The FREE RADICAL CURE system is the oldest crosslinking chemistry used for silicones. It has been commonly called a “high temperature vulcanizing (HTV)” system. This chemistry utilizes free radicals generated by organic peroxides (see Figure 2) that decompose at elevated temperatures, initiating a crosslinking reaction.

$$R^{\cdot} + CH_2 = CH-Si\equiv \rightarrow R-CH_2-CH^{\cdot}-Si\equiv$$

$$RCH_2-CH^{\cdot}-Si\equiv + CH_3-Si\equiv \rightarrow RCH_2-CH_2-Si\equiv + \equiv Si-CH_2^{\cdot}$$

$$\equiv Si-CH_2^{\cdot} + CH_2 = CH-Si\equiv \rightarrow \equiv Si-CH_2-CH_2-CH^{\cdot}-Si\equiv$$

$$\equiv Si-CH_2-CH_2-CH^{\cdot}-Si\equiv + \equiv Si-CH_3 \rightarrow \equiv Si-CH_2-CH_2-CH_2-Si\equiv + \equiv Si-CH_2^{\cdot}$$

$$2\equiv Si-CH_2^{\cdot} \rightarrow \equiv Si-CH_2-CH_2-Si\equiv$$

Figure 2. Silicone Crosslinking Using Radicals

Peroxides are effective at levels around 1%; these materials and their derivative radicals are consumed during the reaction, although by-products remain. These tend to be volatile organic acids, which can be removed by exposing the tubing to elevated temperature for an extended period (post-cure).

Many types of peroxides are commercially available, and these differ in formulation (vehicle components), temperature of decomposition, and decomposition products, which may all effect product contamination.

Any material left in the tubing after cure that is not an intrinsic part of the tubing matrix can be a potential extractable; therefore, choice of cure system can affect the accuracy of drug assays and may also impact drug efficacy.

Impact of Fabrication and Cure Conditions on Quality

With free radical cure systems, the peroxide catalyst is added to the silicone elastomer base and blended by milling. Platinum-catalyzed systems are supplied in two equal (by weight) silicone elastomer base parts. Part A contains the platinum catalyst, and Part B, the crosslinker. Again, thorough mixing by milling is required to ensure the tubing cures homogeneously without flaws like gels or voids. Peroxide cure systems offer less control over cure rates and crosslink distribution than do platinum systems, so the resulting tubing may be less consistent in appearance. Cure is accomplished during extrusion, where temperatures are typically higher than those used for slabs or other fabricated parts due to rapid throughput speeds. Extrusion involves a die that produces a specific cross-sectional shape along a continuous length. Hot air vulcanizing ovens of vertical or horizontal configuration are used. Post-cure of platinum-catalyzed tubings is not necessary as there are no cure by-products, but heat treatment of peroxide-initiated tubings for four hours or longer after cure may be needed to remove cure system residuals.

Perhaps as a result of extensive heat exposure, and due in part to inherent differences in cure mechanism, peroxide-cured tubings are sometimes darker in appearance and more opaque than platinum-catalyzed products. Peroxide-cured materials may also have a higher surface tack, which could translate to faster dust and dirt pick-up.

Translucency may be important if color or visual viscosity checks are part of process monitoring. The impact of bubbles, gels, drag lines and other physical flaws on specific properties is unknown, but it is possible that these tubing wall defects could impact peristaltic pump life and burst performance.

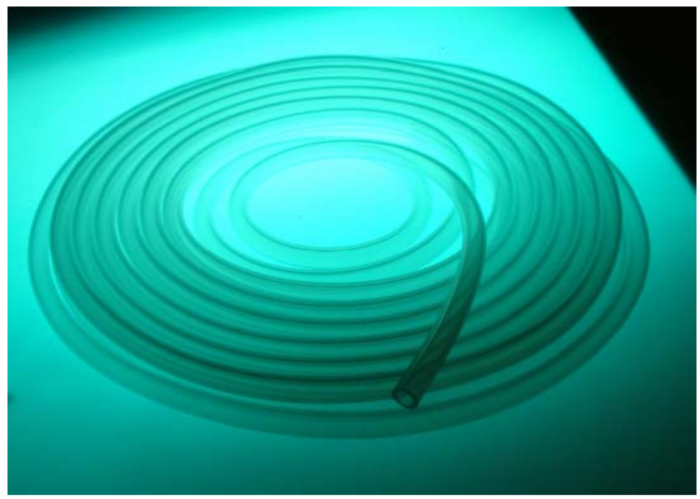
Chemical and Physical Properties Impacted by Cure System

Table 1 gives the physical properties of some peroxide- and platinum-cured elastomers of similar formulation. Although properties such as tensile, elongation and modulus can be affected by catalyst and crosslinker concentration, these data show the differences that can be seen with analogous materials of typical formulation.

Peristaltic pump life is typically higher for peroxide-cured tubings than for standard platinum-catalyzed materials[1]. The generation of abrasion particles during pumping (spallation) is related to pump performance; longer life results in a lower average weight of particles on a per hour of pumping basis.

As mentioned above, residuals in peroxide-cured elastomers and tubing translate into potential extractables which are not present in platinum-catalyzed materials. Extract testing is an important component of the assessment of materials that will come into contact with fluids, especially if residence time is extensive or temperatures and pressures are elevated. Results are highly method-dependent, however, and data comparisons must be done with caution. Parameters such as sample configuration, preparation and storage, as well as solvent choice, time, temperature and surface area-to-volume ratio can each have a significant impact on outcome.

Organic (aromatic) acids in peroxide-vulcanized tubings (which may be present to some extent even after extensive post-cure) are believed to contribute to the pH reduction and Total Organic Carbon seen in water extracts (Table 2.) The post-cure used for peroxide-cured tubing is effective in reducing the extractable levels of low molecular weight siloxanes, however[2].



Summary and Conclusions

Silicone tubing is widely used in the pharmaceutical applications for two major reasons. First, and foremost, is safety. Silicone tubing does not contain plasticizers or other additives that could leach into a drug product and cause toxicological issues. Second, silicone tubing is highly flexible and tear-resistant, making it a good choice for transporting fluids between tanks, or for use in filling machines.

There are cure system options with silicones, however, that produce materials with different characteristics, whose impact should be considered before tubing selection. Silicone materials may be cured using free radical (peroxide) or addition (platinum) cure mechanisms. Peroxide-cured

[1] Dow Corning Advanced Pump tubing, although Pt-catalyzed, has higher pump life than standard Pt-cured products

[2] Summaries of Health Data are available from Dow Corning for tubings and extractable siloxanes

materials have better pump life and reduced spallation relative to standard platinum-catalyzed tubings, but are less translucent and may be more prone to other appearance flaws. In addition, there may be physical property differences between materials cured with these two systems. Peroxide-cured tubings may have higher levels of organic extractables, and produce more acidic extracts, although low molecular weight volatiles are reduced by the extensive post-curing used with these materials. The relative value and impact of these characteristics should be evaluated carefully when selecting tubing for fluid handling applications.

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Table 1. Comparison of Representative Silastic® Peroxide[a]-and Pt-cured[b] Elastomers

Typical Physical Properties

Property	*Units*	*35-Durometer Elastomer*		*50-Durometer Elastomer*		*65-Durometer Elastomer*	
		Pt-cured	Peroxide-cured	Pt-cured	Peroxide-cured	Pt-cured	Peroxide-cured
Tensile Strength	MPa	9.84	8.21	10.16	9.41	7.94	7.59
	psi	1427	1190	1473	1364	1151	1100
Elongation	%	1171	971	903	596	890	590
Modulus at 200%	MPa	1.11	0.97	2.14	2.50	2.82	3.07
	psi	161	140	311	362	409	445
Tear Strength (die B)	kN/m	36.6	24.5	45.9	35.9	45.5	42.2
	ppi	209	140	262	205	260	241

[a]Catalyzed with 2,4 dichlorobenzoyl peroxide, 1% w/w. Post-cured 2 hr at 350°F (177°C)

[b]Cured at 240°F (116°C) for 10 min, no post-cure

Table 2. Comparison of Peroxide-and Platinum-cured Tubing Extractables[a]

Parameter/Extractable	Pharma-50 Tubing (Pt-cured)		Pharma PXS-50 Tubing (Peroxide-cured)	
	Water	Acetone	Water	Acetone
pH change[b]	0	NA[c]	-2.3	NA[c]
Total Organic Carbon (µg/g sample)	2.63	NA[c]	62.73	NA[c]
Residue (mg/g sample)	0	13.3	0	10.51
Total LMW siloxanes[d] (µg/g sample)	NA[c]	10241	NA[c]	3837

[a]3/8" x 5/8" tubing
[b]Relative to control
[c]Not applicable; assays cannot be performed in this solvent
[d]**L**ow **M**olecular **W**eight siloxanes are linear and cyclic siloxanes through D20; these materials/levels have no negative biological effects[3]

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