

21. Silicones and Their Impact on the Environment

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A large number of studies have been conducted to evaluate the fate and effects of silicones in the environment throughout their life cycle [1]. Releases to the environment from the manufacture of polydimethylsiloxane (PDMS) are strictly controlled and must comply with emission limits specified by regulatory authorities. Subsequently, the environmental fate of silicones depends to a large extent on the nature of the application, the physical form of the material and the method of disposal. Low molecular weight PDMS polymers (< 1000 Da) are primarily used in personal and household care products. High molecular weight PDMS polymers are important as antifoams and lubricants for domestic and industrial use. However, a more important application is as a “solid” silicone such as PDMS-based rubbers or sealants, both of which may be used either in the home (e.g., bath sealants, bake-ware or baby teats) or diverse industrial applications such as textile coatings, electronics, silicone mouldings and rubber gaskets.

“Solid” silicones enter the environment as a component of domestic or industrial waste and will be either land filled or incinerated. In the latter case, they are converted back to inorganic ingredients, amorphous silica, carbon dioxide and water vapour. “Liquid” silicones, both high and low molecular weights, which are used in rinse-off products such as shampoos, hair conditioners or silicone antifoams in detergents, become part of municipal wastewater. The same is true for PDMS used as antifoams in pharmaceuticals. High molecular weight silicones are virtually insoluble in water, thus, as a consequence of their high binding potential for organic matter, they are effectively removed from municipal wastewater onto the sludge during wastewater treatment. Extensive studies show that more than 95% of silicones are removed from effluents in this way, and that the concentration in discharged effluents borders the level of detection ($5 \mu\text{g/l}$) [2-3].

The subsequent fate of silicones depends on the fate of the sludge. If incinerated, silicones degrade as indicated above. The other principal outlet for sludge is use as a soil conditioner or amendment. In small-scale field studies, the application of sewage sludge-bound PDMS to soil caused no observed adverse effects on crop growth or soil organisms [4]. Little or no uptake into the plants was observed, which is consistent with animal studies showing that high molecular weight PDMS is too large to pass through biological membranes of either plants or animals. Extensive studies ranging from small-scale laboratory tests to field studies show that sewage-sludge bound PDMS degrades in soils as a result of contact with clay minerals [5-6-7-8-9-10]. The clay acts as a catalyst to depolymerise the siloxane backbone [10-11]. The primary degradation product, regardless of the PDMS molecular weight, is dimethylsilanediol, $\text{Me}_2\text{Si}(\text{OH})_2$ [6]. Depending on the soil type, this undergoes further degradation either in the soil via biodegradation [11-12] or evaporates into the atmosphere, where it degrades oxidatively via reaction with hydroxyl radicals [13]. Whether degradation occurs in the soil or in the air, there is conversion to inorganic constituents, amorphous silica, carbon dioxide and water.

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