Silicone environmental impact: from its origin to its fate

Vervier, Ingrid[1*]; Dihang, Hélène [1]; Plotzke, Kathleen [2]

[1] Dow Home & Personal Care, Dow, Seneffe, Belgium;[2] Dow Home & Personal Care Product Stewardship, Dow, Auburn, United States

*Vervier Ingrid, Rue Jules Bordet, B-7180 Seneffe, Belgium, +32.64.88.80.00, ingrid.vervier@dow.com

Abstract

Silicones are a broad chemical family that take numerous forms. Silicones have a long-standing history of safe use in personal care, health care and other consumer product applications because they make existing materials work better, more efficiently, longer and more reliably.

Most silicone polymers can be considered of partial mineral origin given silicon, the second most abundant element in the Earth's crust.

Silicones are one of the most extensively studied class of materials. Because of their unique properties, these types of substances are all resistant to biodegradation using standard OECD testing protocols such that they are typically considered not readily or inherently biodegradable by these international definitions. However, abiotic degradation mechanisms are important in the fate of silicones in the environment and often are overlooked as to their role in removing these substances from the environment.

Unclear and confusing information around the impact of silicones on the planet and on human safety have caused consumer concern. With data, we want to bridge the gap and lead a transparent science-based dialogue.

Keywords: (4-6 keywords separated by a semicolon). Sustainability, environment, degradability, silicones

Introduction

With a long-standing history of safe use in personal care, silicones have changed the face of the beauty industry. They have unique, long-lasting properties that enable increased efficiency of finished formulations [1]. These properties fuel our imaginations, enable continuous performance innovation, and contribute to a more sustainable future. Unfortunately, there are misperceptions regarding the impact of silicones on the planet and on human safety which create consumer concerns.

[2] Silicon (Si), the starting point for all silicone materials, is the second most abundant element in the earth's crust after oxygen, and is available under the form of quartz, sand, and even plant husk. Derived from quartz, composed of silicon and oxygen atoms, silicones are a broad family of polymers providing a wide range of materials with problem-solving benefits. In addition, silicone chemistry can be engineered to deliver beauty care ingredients from low viscosity volatile fluids to viscous or solid materials.
The most well-known structure of a silicone polymer is called polydimethylsiloxanes (PDMS) and contains repeated sequences of silicon and oxygen atoms, surrounded by methyl groups (Figure 1). The performance of these polymers can be fine-tuned depending on the targeted benefits. For example, silicone polymers can be modified by varying the molecular weight, changing the structure to form a tri-dimensional crosslinked resin and/or adding other organic functionalities. The addition of organic chains helps oil or water compatibility [3], increases formulation flexibility and/or allows superior affinity for skin or hair. This can also lead to a range of sensory attributes, gaining consumer acceptance, trust, and loyalty.

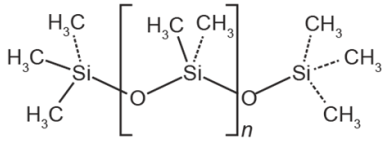

Figure 1: Traditional representation of polydimethylsiloxanes

Methods

Silicones are one of the most extensively studied class of materials. Because of their unique properties, these types of substances are all resistant to biodegradation using standard OECD testing protocols such that they are typically considered not readily or inherently biodegradable by these international definitions. However, abiotic degradation mechanisms are important in the fate of silicones in the environment and often are overlooked as to their role in removing these substances from the environment. It is important to first understand the distribution and fate during their use to identify the most relevant environmental compartments where they may be found followed by characterization of relevant degradation processes that may be involved in their overall environmental removal.

Results

Most silicones used in personal care applications are not expected to reach the water environment to a significant degree, as, after application, they will have either evaporated (volatile siloxanes) from skin or hair, or when they are washed off through water and go down the drain, they will be partitioned out of the wastewater by binding to suspended particulate matters. In wastewater treatment plants, they will end in the sludge by sedimentation**.** The sludge is either handled as waste or it may be used to spread on land for agricultural purposes. Once in the soil, silicones are degraded by the clay in the soil [3]. Silicones are considered not readily biodegradable under standard testing (i.e. OECD guideline testing for biodegradation) but the consideration of biodegradation alone does not give a complete picture of the potential for silicones to be degraded once they reach the environment [4].

Indeed, studies taking into consideration physicochemical properties show that silicones are degradable by hydrolysis either in soil or sediments for volatile and non-volatiles polydimethylsiloxanes or in the air by photolysis for the volatile siloxanes such as the cyclic siloxanes [5], [6], [7].

In soil, depending on humidity and pH conditions, PDMS are expected to be ultimately converted to silica, silicic acid, and carbon dioxide most likely via both chemical and biological degradation processes, leading to the removal of silicones from the environment [3] [8].

Discussion

Most silicone polymers can be considered of partial mineral origin given silicon, the second most abundant element in the Earth's crust.

The transformation of silicon dioxide (SiO_2) into silicon metal is an energy-intensive process but can be produced in a highly sustainable way. For example, in Brazil, Dow has a silicon metal facility that uses hydroelectric power with a minimal impact on the environment. At the site, Dow owns 45,000 hectares of land – about 80% of which is preserved native Amazon rainforest and about 20% of which is an eucalyptus plantation.

Charcoal used in silicon metal production is made from eucalyptus that is sustainably cultivated and harvested from the plantation per Forest Stewardship Council (FSC) guidelines. Dow recently initiated Project Ybá, which will map the biodiversity of the forestland for bioactive ingredients and help develop a local cooperative that will harvest and sell them. With the launch of this project, Dow is playing an active role in contributing to the social development of the Brazilian Breu Branco community, as more than 150 families in the region are expected to benefit through employment in a sustainable industry. Through the identification and sale of bio-active products for the cosmetics industry, this initiative can increase the income for families, while contributing to the conservation of part of the Amazon rainforest.

Silicone polymers used in personal care products are typically chemically inert and non-reactive bio compatible ingredients that are stable substances under usual environmental conditions. Non-functional silicones are colorless and odorless. Derived from mineral, none of the PDMS components are derived from GMOs or animals, meaning most silicones are ideal clean beauty, vegan-friendly, and cruelty-free ingredients by default. Their unique chemistry resists oxidation and they typically do not cause skin irritation or have any allergen or drying effects. The above combined with their ultimate removal from the environment help support the sustainability of silicones.

Conclusion

Silicones have a long-standing history of safe use in personal care and consumer product applications because they allow existing materials to work more efficiently with longer-lasting performance. They have a large number of unique, long-lasting benefits in personal care applications, and can contribute to a more sustainable future. They fuel our imaginations and make new products possible. In a society that runs on performance and strives for sustainability, silicones are an invaluable and unique source of inspiration.

Conflict of Interest Statement. NONE.

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