The Power of Silicones in Cosmetic Applications: The Science behind the Performance

S. Marchioretto, I. Vervier, I. Van Reeth, K. Plotzke, B. Johnson
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. This article bridges the gap between myths and facts for the purpose of encouraging a transparent science-based dialogue. It covers safety, sustainability, and performance benefits – but it all begins with the unique chemistry of silicones.

Silicone Chemistry [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).

![Traditional representation of polydimethylsiloxanes](Fig. 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.

Silicone Chemistry Physicochemical properties [2, 3]

Their distinctive physicochemical properties are the reason why silicone polymers offer unique performance and benefits. They display an unusual combination of inorganic high surface energy from the Si-O-Si chain with side methyl groups that are organic and often associated with low surface energy. Thanks to the methyl groups, silicone polymers weakly interact with each other (Figure 2).

Compared to C-C or C-O based-polymers, Me₂Si-O repeat unit polymers possess:
- Lower rotational energy around the Me₂Si-O- bond
- Wider Si-O-Si bond angle
- Longer Si-O bond length
- Strongly polarized Si-O bond

These characteristics lead to fascinating polymers with physicochemical properties such as:
- Low surface tension, resulting in efficient wetting and high spreading [4].
- High polymer flexibility, enabling the siloxane chain to adapt its conformation to its environment. So, when applied on typically polar skin or hair surface, the silicone polymers expose their polar high surface energy Si-O-Si chain towards the substrate, creating a relatively substantive film. In this conformal arrangement, the methyl groups of lower surface energy orient outward forming an efficient hydrophobic top layer (Figure 2). This flexibility also enables silicones to smoothen surfaces, hence leading to unique skin and hair feel. [4], [5], [6]
- Low glass transition temperatures (Tg: -127°C) [3], hence remaining fluid even with high molecular weight, unless modified e.g. with more rigid organic substituents such as aryl groups.
• High solubility and high diffusion coefficient of gas into silicones resulting in high permeability to oxygen, nitrogen and water vapour.
• High resistance to UV, heat, and oxidation.
• Tunable refractive index from 1.4 to 1.6 depending on the organic group substituent.

b. Silicone sustainability
In a world that strives for sustainability, silicone polymers can play a key role. The following is a review of silicone sustainability in terms of degradability, feedstock, and benefits for eco-conscious consumers.

1. Silicone degradability [16]
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 may be used to spread on land for agricultural purposes. Once in the soil, silicones are degraded by the clay in the soil [17].

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 [18].

Indeed, studies taking into consideration physicochemical properties show that silicones are degradable by hydrolysis either in soil or sediments for volatile and non-volatile polydimethylsiloxanes or in the air by photolysis for the volatile siloxanes such as the cyclic siloxanes [16], [19], [20].

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 [7], [17].

2. Sustainable feedstock
The transformation of silicon dioxide (SiO₂) 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 [21], 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 of families, while contributing to the conservation of part of the Amazon rainforest.

3. Benefits for eco-conscious consumers

In hair care, silicones, particularly aminosiloxanes, are used to protect hair against daily grooming damage thanks to the excellent lubricity obtained from their low surface tension. Silicone deposition along hair fibers helps to restore the healthy look and feel of damaged hair cuticles, providing a perception of moisturization. They are also well-known for enhancing hair shine [22].

In skin care, silicones offer a luxurious and silky feel, contributing significantly to the consumer's adoption of a formulation [23]. Silicone elastomers are critical ingredients used in "skin primers" to minimize the appearance of the pores and fill in fine lines and wrinkles, smoothing skin surface [24], [25]. They are also widely used for their sebum absorption properties, mattifying greasy skin [24], [25].

Eco-conscious consumers as well as hair and skin beauticians look for cosmetic products that save energy, reduce water consumption and waste, and potentially extend the life of their beauty devices.

Silicone materials are well-positioned to meet these sustainable requirements as most silicone polymers:

- Typically have low odor, low color, and high purity [26]
- Are offered without preservative when supplied as polymers
- Remain stable under in-use conditions, hence, have a long shelf life and do not need specialized storage conditions
- Are processable at room temperature
- Can be used at relatively low levels, allowing improved performance in high natural content formulations [27]
- Have high spreading properties and long-lasting performance, helping reduce the amount and frequency of application

Furthermore, silicones can:

- **Protect colored hair from fading:**
  Certain silicones help retain color vibrancy up to the next coloration despite repeated washes imposed by hair grooming routine [28]. In most hair colorant systems, silicones are also widely used during the process to restore hair smoothness and shine. Examples of best-performing silicones for color retention include DOWSIL™ CE-8411 Smooth Plus Emulsion and DOWSIL™ S-7114 Silicone Quat Microemulsion.
- **Aid hair styling:**
  Once washed, hair fibers treated with DOWSIL™ 8500 Conditioning Agent, DOWSIL™ CE-8411 Smooth Plus Emulsion, or HydroxySHIELD™ Polymer become more hydrophobic and less tangled. This leads to faster air or blow drying. If curly hair is left to dry at room temperature, curl definition is significantly improved. Even straight hair is less frizzy when treated with silicones like DOWSIL™ CE-7081 Smart Style or DOWSIL™ 3901 Liquid Satin Blend.

When the use of electrical appliances such as straightening or curling irons are needed, the time to style the hair can be reduced when using formulations containing DOWSIL™ CE-8411 Smooth Plus Emulsion, DOWSIL™ 969 Emulsion, or DOWSIL™ AP-8087 Fluid [29]. Once hair is styled, the more hydrophobic hair fibers provide prolonged hair shape, whether curled or straightened, diminishing unpleasant frizz, even under high humidity conditions.

Additionally, because silicones are thermally stable and form a water vapor permeable film all along the cuticle, they guard against heat damage. Silicone gum blends such as DOWSIL™ 1507 Fluid and DOWSIL™ 1508 Fluid [30] are efficient heat protectors when used in anhydrous serums. Because specific OH amino-functional silicones – such as DOWSIL™ CE-8411 Smooth Plus Emulsion and DOWSIL™ 969 Emulsion – prefer to deposit on damaged areas of hair and cuticle edges, they further prevent hair cuticle damage from heat. These properties assist formulators in using natural products such as argan oil but without the drawback of their damaging effect when used at temperatures up to 230°C.

- **Counteract negative effects of pollution:**
  Daily exposure to urban pollution particles has a negative impact on hair shine and combing force. DOWSIL™ HMW 2220 Non-Ionic Emulsion in aqueous leave-in conditioners, or DOWSIL™ AP-8087 Fluid in anhydrous gum blend serums, help to counteract these effects. Even better, by decreasing polarity and increasing hydrophobicity of hair fibers, DOWSIL™ 3903 Liquid Satin Blend based serums reduce the amount of pollution depositing on hair. Therefore, hair looks and feels good despite exposure to a polluted environment.

In skin care, silicone such as DOWSIL™ FA 4103 Silicone Acrylate Emulsion or DOWSIL™ FA 4004 ID Silicone Acrylate are also ideal solutions to reduce the adhesion of particulates to the skin in polluted areas like cities [31]. These properties reduce the number of washes and/or facilitate them, preserving water and energy consumption.

- **Improve product spreadability:**
  Silicones contribute to an improved formulation spreadability on both skin and hair. In sun care, superior skin coverage of sunscreens is achieved, optimizing skin protection against UV damage [32]. In color cosmetics, when DOWSIL™ FZ-3196 Fluid [33] is used, pigments form a more uniform film that may lead to less product usage.

- **Provide longer-lasting benefits:**
  Film-forming silicones such as DOWSIL™ FA PEPS Silicone Acrylate impart resistance to friction and water to color cosmetic or sun care formulations [34]. These properties provide transfer resistance benefits even in presence of...
sebum. The comfort of wear is maintained thanks to the high flexibility and permeability of the silicone acrylate hybrid polymer.

- Enable superior feel of high natural and derived natural ingredient containing formulations:
  Thanks to their bio-based carrier, DOWSIL™ 1508 Fluid or DOWSIL™ EL TIPS Silicone Elastomer Blend allow products to be formulated with an exceptional feel and texture with a natural content of more than 90% [35]. These blends also enable to formulate water-free formulation, another interest for eco-conscious consumers.

**Silicone Truths vs Myths**

Over the years several myths have developed concerning personal care products containing silicone. In the interest of science, below are three facts that dispel the most common myths.

1. **Silicone does not build up on hair: True!**
   Because of their low intermolecular forces, PDMS formulations spread evenly on the hair fiber until a monolayer is covering the hair surface. Therefore, they do not accumulate in layers. This means no “build-up” effect when using the recommended amounts, depending on hair types.

   Multiple Dow studies show that hair maintains its healthy look (no volume loss, enhanced shine without greasy look) and lightweight feel, even after 20 shampoo and/or rinse-off conditioner applications.

   Additionally, Dow demonstrated that the silicone deposition from a DOWSIL™ CE-8411 Smooth Plus Emulsion based shampoo (1% silicone active) is not cumulative even after 10 repeated treatments (Figure 3).

2. **Silicones are washable: True!**
   With a relatively weak bond between the silicone and the hair or skin surface, PDMS will be easily removed after the use of a clarifying shampoo or a shower gel [36]. On hair, Figure 4 shows that the silicone deposited after 10 shampoo treatments alone (as referenced above) or 10 shampoo and rinse off conditioner applications can be removed when post washed with a clarifying shampoo.

   Most silicones deposited on the skin are also removable when surfactant-based formulations are used. However, some of them have been designed to resist to rub off or sebum secretion, an ideal benefit e.g. for long-lasting color cosmetics. DOWSIL™ EL-7314 Silicone Elastomer Blend has been particularly designed to provide long color cosmetic skin remanence up to five days, making it an ideal additive for semi-permanent tattoos. (Figure 5).

![Fig. 3 Silicone deposition up to 10 shampoos (ICP-OES)](image)

![Fig. 4 Silicone removability with a clarifying shampoo (ICP-OES)](image)

![Fig. 5 Color rub-off resistance of a mascara coated on a skin-mimicking substrate after friction cycles on a felt band (Colorimeter)](image)
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.

**References:**


[20] The unique properties of siloxanes, CES Silicones (Centre Européen des Siloxanes)/European Chemical Industry Council (CEFIC) Europe.


©™ Trademark of The Dow Chemical Company (‘Dow’) or an affiliated company of Dow


[34] “New Personal Care Ingredients from Dow Boost Sustainable Products and Natural Connections for Beauty Brands,” SOFW, 18 April 2019.
