18. Silicone Lubricants in Industrial Assembly and Maintenance

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In this industrial segment, silicones are used as sealants or lubricants. Lubricants will therefore be the focus of this section. Silicone lubricants are not limited to assembly and maintenance, as they are also used in other industries like the automotive, chemical or food industries.

Historically, silicones have been used as lubricants right from the start of the industry in the form of a silica-thickened PDMS compound, which is sometimes referred to as a “noncuring sealant,” and well known to chemists as “vacuum grease” for lubricating glassware joints [1]. This application highlights the properties of silicones that make them superior to other lubricating liquids in some applications; for example, their possible use over a wide range of temperatures from synthesis at low temperatures as with liquid ammonia to distillation under vacuum at high temperatures.

Tribology and Lubrication Mechanism

Tribology is the engineering discipline that studies the friction and wear phenomena occurring between two moving surfaces in contact with each other as well as the mechanism of lubrication.

Friction is physically characterized by the coefficient of friction and as the ratio of the force required for moving two surfaces to the applied force perpendicular to the moving direction. Friction consists of an adhesive and a destructive component. The latter results in wear of various forms [2]. Coefficients of friction range from 0.0001 to 0.0005 for air bearings as used in dental drills up to 0.3 to 0.5 for automotive brake systems. Lubrication is basically a reduction of both wear and friction by generating a lubricating film between the moving surfaces. There are three modes of lubrication characterized by the ratio of lubricating film thickness to the sum of both surfaces’ roughness:

- Boundary lubrication, when the ratio is smaller or equal to 1, and when the surface asperities interfere with each other resulting in a high coefficient of friction
- Mixed lubrication, when the ratio is between 1 to 5, and when the surface asperities occasionally interfere with each other due to load variation
- Fluid film lubrication, when the ratio is larger than 5, and when a complete separation of the two moving surfaces is achieved, resulting in a low coefficient of friction

The generation of a fluid lubricating film can be achieved by pressurizing the lubricating fluid via an external pump as done for turbine start-ups, but this is an exception. In the majority of fluid film lubrication, the geometries are designed in such a way that the necessary pressure is built internally within the fluid itself by the velocity of the surfaces in movement. The velocity profiles in the lubricating contact zone are a combination of Couette’s flow with linear velocity distribution and Poiseuille flow with a parabolic velocity distribution. The fluid flow is forced through a wedge that generates a pressure profile according to Bernoulli’s law. The pressure generation is similar to that of aircraft wings. In this analogy, one can compare the change from mixed to fluid film lubrication with the takeoff of an airplane, which is the minimum of the curve in Figure 1 (see further) [3].

So, the concept of lubrication is to separate two moving surfaces with a “softer and easier-to-shear” liquid material or lubricant located between the surfaces, and to build up enough pressure in the liquid to separate the two moving surfaces and reduce the coefficient of friction or the force needed to move them against each other under an applied load. As seen in Figure 1, at low speeds the lubricant does not have sufficient internal pressure to separate the two slow-moving surfaces, resulting in high friction. As speed increases, the internal pressure induced by shear in the lubricant separates the two moving surfaces and brings the coefficient of friction to a minimum. At higher speeds, the coefficient of friction increases again due to the work required to shear the lubricant.

Figure 34 also shows that for lubricants of similar composition but of different viscosities, the higher the lubricant viscosity, the earlier surface separation or lubrication occurs, and also that optimum performance is therefore a function of the applied shear, or a corresponding rotational speed in many cases.

This shows that successful lubrication depends on the selection of the most suitable fluid vs. the particular application conditions like speed as well as load, environmental aggressions and temperature.

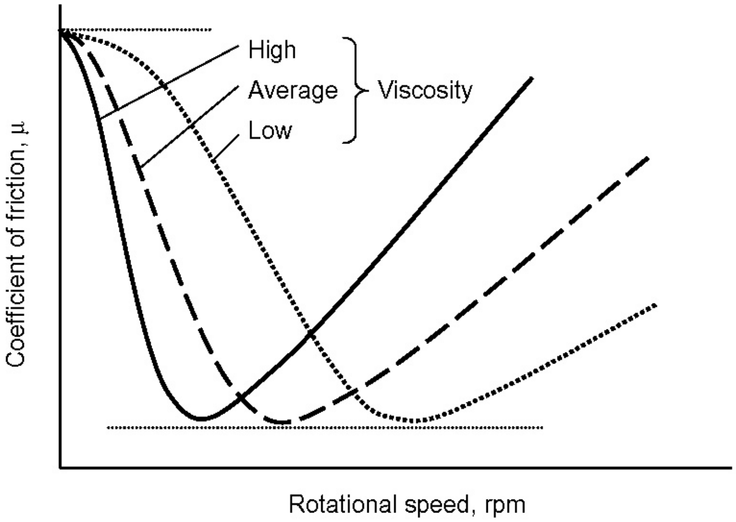

Figure 1. ***Coefficient of friction vs. rotational speed in a journal bearing, a plain bearing without rolling parts. (Picture courtesy Dow Corning GmbH.)***

Polymeric Lubricant Composition

Among various liquids, polymeric materials have come out as the best option for lubrication. If considering the Mendeleev table, only two elements are liquid at room temperature, bromine and mercury, but neither is suitable as a lubricant (due to reactivity and toxicity). As liquid, water also comes to mind. But even though water has good lubricating properties as demonstrated by floating movements of boats and various ice compressing forms of movement, the limitation is that water is only available in one single and low viscosity, and it is liquid only in a narrow range of temperatures; not to mention its corrosiveness that further precludes its use as a lubricant. Actually, the same holds true for many other low molecular weight chemical species.

So, this explains why lubricating fluids are mostly polymeric in nature; for example, organics such as mineral oil based fluids with various degrees of paraffinic, naphtenic or aromatic content. Or, they may be synthetic fluids like poly alpha olefins, neopolyol esters, polyalkylene glycols, dibasic esters, phosphate esters, polybutenes, dialkylbenzenes and perfluorinated polyethers, as well as silicones like PDMS [4].

Because of their low Me-to-Me intermolecular interactions and high backbone flexibility, PDMS materials have a low Tg and are liquid at room temperature, even if of high molecular weight. PDMS materials have high boiling points, and their viscosity is less affected by temperature changes than organics. These properties make PDMS polymers interesting as possible lubricants. Yet as their surface tension is low, they tend to spread on surfaces more than organic lubricants.

High spreading and high compressibility limit the internal pressures that can build within PDMS materials when used as lubricants and limit their load-carrying capacity if compared to organic lubricants of the same initial viscosity.

Today, three types of silicones are used as lubricants in industrial assembly and maintenance applications:

- Dimethyl siloxane polymers (PDMS, known as dimethyl silicone)
- Phenylmethyl dimethyl siloxane copolymers with phenyl substitution from 10 to 90% (known as phenyl silicone)
- Trifluoropropylmethyl dimethylsiloxane copolymers (known as fluorosilicone)

Silicones, like mineral oils and most synthetic lubricant fluids, are also compounded with thickeners such as metal fatty acids to give lubricating greases capable of keeping the lubricating fluid in close contact with the surfaces in movement. The thickener can be pictured as a sponge that holds the lubricating fluid in place, and such greases are used when total sealed enclosure is not possible. The fluids are further formulated with additives to improve the physical properties of the fluid itself or to add capabilities for mixed and boundary lubrication. Such formulations still represent a challenge for silicones beyond fluid film applications; the range of available additives is limited because these additives were tailored for organic-based materials.

Examples of Silicone Lubricant Applications

Each lubricant application is characterized by its specific operating conditions, which are load, environmental aggressions, temperature and speed.

Load is a limiting factor for silicone lubricants, particularly in metal-to-metal lubrication; so when other conditions require a silicone lubricant, the dimensions of the lubricating contact surfaces may need to be increased. Fluorosilicone lubricants have higher load-carrying capacity due to their higher adhesion to metal substrates. However, for all metal-to-plastic or plastic-to-plastic combinations, silicone lubricants have sufficient load-carrying capacity.

Environment aggressions have less effect on silicones if compared to organic lubricants. The oxidation resistance of silicones makes them suitable for long-life applications. Because of their inertness to most chemicals, silicone lubricants are widely used in the chemical industry, and also in food and beverage processing. Though the load-carrying capacity makes silicones a candidate for plastic lubrication, it is their inertness with almost all plastics or elastomer materials that makes them ideal in these applications. Poor compatibility is experienced only when silicones have to lubricate silicone elastomer surfaces because of the swelling they induce in the silicone elastomers.

Temperature capability of silicone-based lubricants is unsurpassed as covering the widest range.

Speed or better "high shear by design" is required for silicone lubricants in metal-to-metal applications so as to generate enough internal pressure and load-carrying capacity. For plastic lubrication and when using a fluorosilicone lubricant, lower speeds are possible.

Table 1 compares the three types of silicones used as lubricants vs. organics [5].

Table 1. Silicone Lubricant Properties vs. Those of Organics

Lubricant	***DP (*)***	***MW** Da*	***Viscosity at 40 ºC** cSt*	***Pour point** ºC*	***Flash point** ºC*
Poly alpha olefine (PAO)	20 -60	150 -450	5 -50	-63 to -57	165 -258
Perfluorinated polyether (PFPE)	10 -180	1100 -13,000	4 -500	-90 to -30	n.a.
Dimethyl silicone	20 -1,300	1,500 -100,000	15 -45,000	-60 to -41	230 -316
Phenylmethyl silicone	70 -500	5,600 -40,000	40 -700	-73 to -13	275
Fluorosilicone	40 -100	5,000 -10,000	150 -5,300	-47 to -32	260 -316

*DP: degree of polymerization

Practical examples are given in Figure 2 through Figure 5 [6].

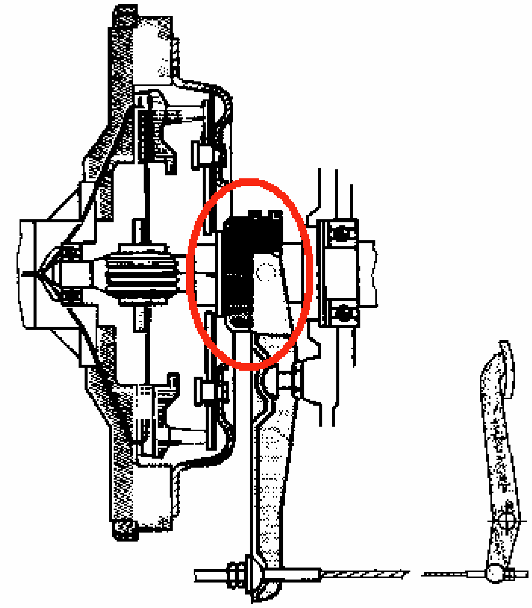

Figure 2. Clutch release bearing with a phenyl silicone grease, which has wide temperature capabilities. (Picture courtesy of Dow Corning GmbH.)

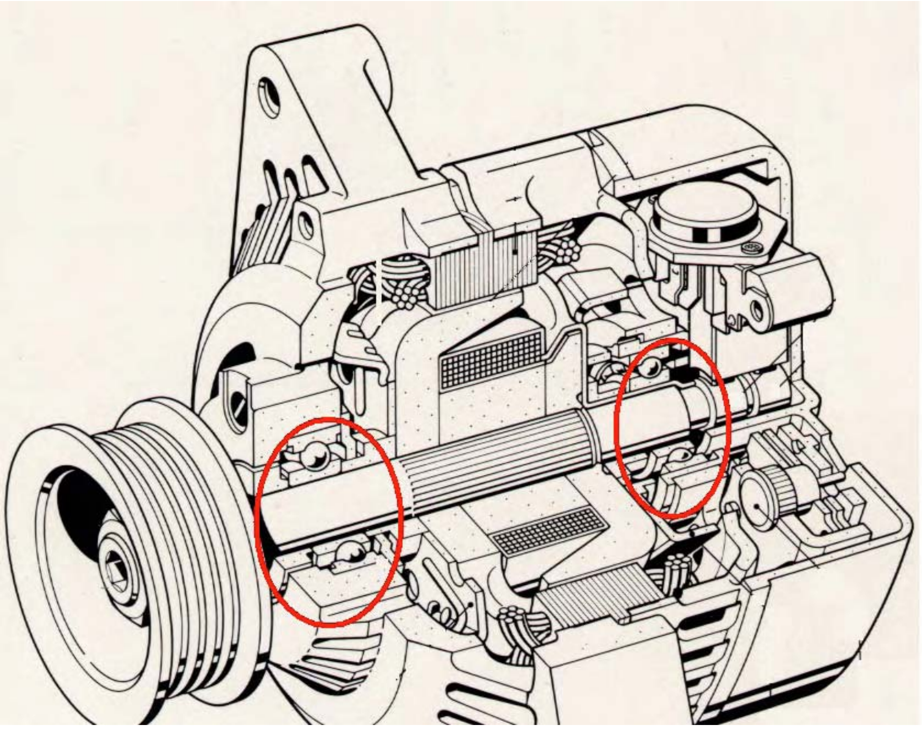

Figure 3. High power alternator and bearings lubricated with a fluorosilicone grease, which offers resistance to high temperatures. (Picture courtesy of Dow Corning GmbH.)

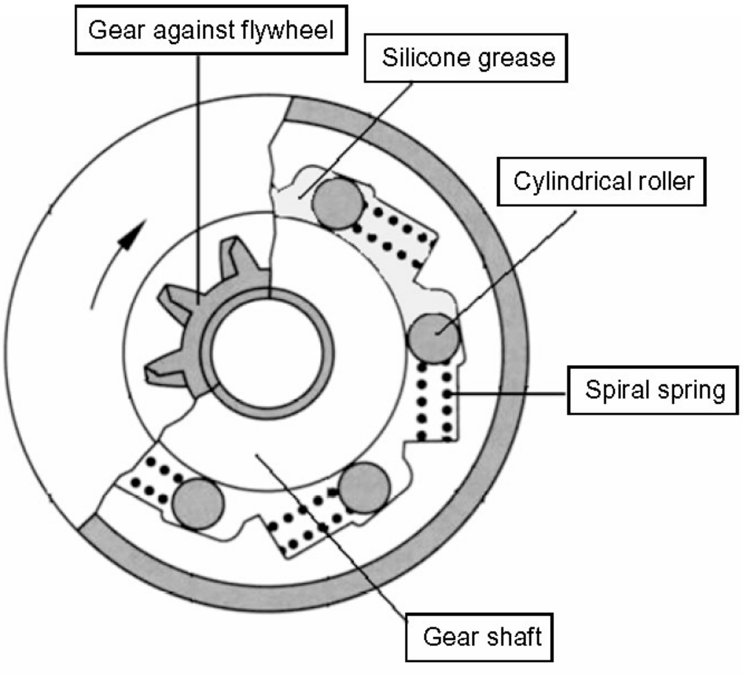

Figure 4. Starter motor with silicone grease lubricant, which provides wide temperature capabilities and a high coefficient of friction to allow decoupling and prevent slippage. (Picture courtesy of Dow Corning GmbH.)

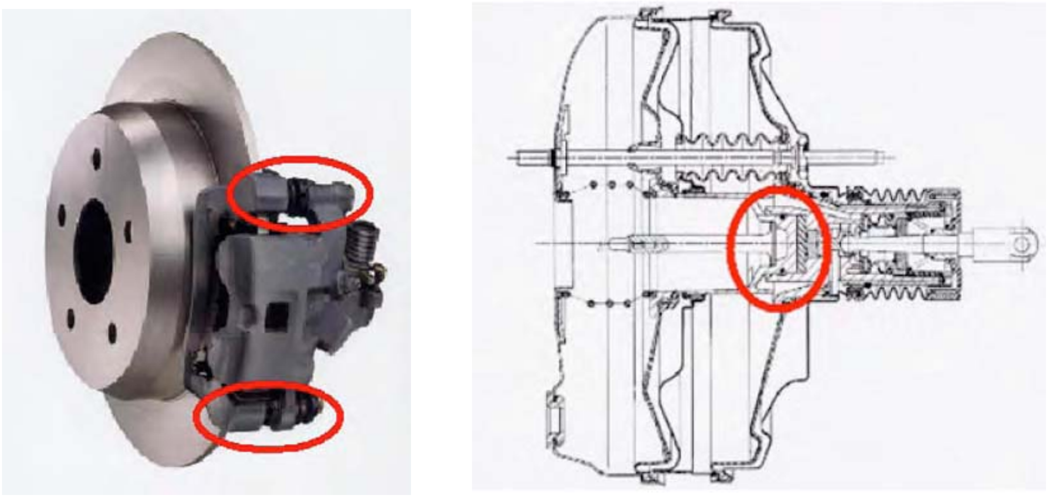

Figure 5. Brake systems (right to left, calliper guides and brake booster) with silicone lubricants, which give wide temperature capabilities and compatibility with plastics and elastomers. (Pictures courtesy of Dow Corning GmbH.)

References

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This article has been published in the chapter “Silicones in Industrial Applications” in *Inorganic Polymers*, an advanced research book by Nova Science Publishers (www.novapublishers.com); edited by Roger De Jaeger (Lab. de Spechtrochimie Infrarouge et Raman, Univ. des Sciences and Tecn. de Lille, France) and Mario Gleria (Inst. di Scienze e Tecn. Molecolari, Univ. di Padoa, Italy). Reproduced here with the permission of the publisher.