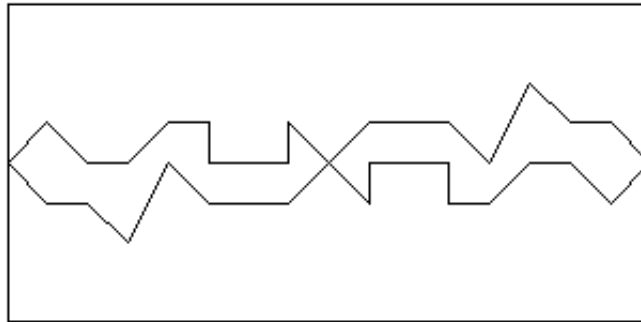


# How Lubricants Work

An understanding of how lubricating systems work is crucial to the selection of a lubricant for a particular application. This essay could be summarized in one sentence: lubricants provide a protective film that separates the two rubbing surfaces and reduces the level of friction in the two rubbing surfaces.

Any surface contains irregularities, even when polished to a mirror finish. These irregularities may not be visible, except under a microscope. When two highly-polished surfaces are brought gently together, only some points on the surfaces will make contact. These contacts will be brought closer together when a force is applied at right angles to the surfaces (this force is referred to as a 'normal load'), and the number of contact points will increase:



If a protective film were present on each of the surfaces, the surfaces could be separated:



to flow more difficult. This is why lubricants with longer carbon chains are thicker than lubricants with shorter carbon chains.

A lubricant with a longer carbon chain is less volatile. As the temperature increases, the molecules vibrate more vigorously until the vibration causes the weak intermolecular bonds to break. As they break, molecules become free to float away or evaporate. Molecules with longer carbon chains vibrate less at a given temperature because they have more mass, so they are less likely to evaporate. Situations in which a lot of heat is generated, such as a car engine, require oils that will not evaporate easily. Bearings with slow-moving parts do not experience such levels of heat, so a different lubricant is required. A lubricant with larger molecules should be used to minimize evaporation, particularly on bearing surfaces that are subjected to high torque and low speeds (revolutions per minute). However, thicker lubricants can interfere with the action of the mechanism when applied to bearing surfaces that are subjected to very low torque and high speeds, so a thinner lubricant must be used, even though thinner lubricants are more likely to evaporate! The purpose of application is particularly important in selecting a lubricant because of the need to consider heat, torque and speed. If a shaft rotates very quickly in a bearing, the fast motion has the effect of bringing more lubricant into the bearing, called a hydrodynamic effect, which increases the separation of the rubbing surfaces. Slower-moving applications do not benefit from the hydrodynamic effect.

You will have noticed that water boils at 100° Centigrade: at 99°, it is a liquid; at 101°, it is a gas. Water freezes at 0°, again within a similarly narrow range of temperatures. Oils, however, solidify gradually as the temperature becomes colder, slowly becoming thicker and thicker until the oil no longer flows: oils solidify over much wider temperature ranges because oils are manufactured as blends of many different oil molecules mixed together to modify the lubricating and thickness properties of the combined mixture. There are many different compounds with the same number of carbon and hydrogen molecules, so while they have the same empirical formula, such as  $C_{18}H_{38}$ .

Their structures are all different, as are their lubricating and thickness properties. Different compounds with the same empirical formula are called isomers. Lubricants can be prepared with blends of isomers as well as with blends of molecules of different lengths of carbon chain to further modify the properties of the combined mixture, which solidifies over a wider range of temperatures and becomes a solid at a lower temperature than an equivalent oil with just one type of molecule (one isomer). Chemical engineers can therefore prepare a lubricant suited for each application, or a lubricant suited for a wide variety of applications. This is called the Base Oil.

The major mineral oil components are paraffinic, naphthenic, and a smaller amount of aromatic compounds. Paraffinic oils are straight chain (as in the example above) or branched aliphatic hydrocarbons (in other words: alkanes and their isomers). Naphthenic oils have saturated hydrocarbons (alkanes) that have at least one closed ring of carbon atoms. Aromatic compounds have one or more benzene rings in each molecule. The variations in composition directly affect the lubricating properties of the blended mixture. Other chemicals are added to the base oil to improve the properties of the oil. Mineral oils react with oxygen at hot temperatures to form hydroperoxides, followed by organic acids, which cause the formation of sludge and varnish and the corrosion of metal parts. Chemicals called oxidation inhibitors are added to the base oils to prevent the deterioration of the oil and the corrosion of metal parts. Similar chemicals called rust inhibitors are added to protect steel parts. Dispersants and detergents

are added to help dissolve contaminants and sludge so that deposits are not formed. Other chemicals, such as anti-wear and anti-scuff additives, that are sometimes added to base oils, react with the metal atoms on the surfaces to form a protective layer that has a lower friction than that of the metals rubbing against each other.

Applications that involve higher levels of torque and slower speeds (obviating the hydrodynamic effect), require lubricants that can adhere more strongly to the metal surfaces. With weaker bonding, the lubricant molecules can be sheared off by the action of the surfaces, and these molecules must be replaced immediately by other molecules. Stronger bonding can be achieved on metal surfaces by using a lubricant that has polarized molecules (at one end), such as a metallic soap like lithium stearate. The polarized end of the molecule is attracted to the metal surfaces while the long alkyl group forms part of the protective blanket that covers the surface. The metallic soap will have a lower melting point than a comparable but nonpolarized alkane because of much stronger hydrogen bonding between the polarized molecules, compared to the much weaker (van der Waals) intermolecular forces. The hydrogen bonding between the molecules also strengthens the protective blanket that covers the surfaces. If you buy an automotive wheel-bearing grease that says 'lithium base' on the container, it would probably contain lithium stearate or a similar lithium soap.

Graphite is an excellent additive because its layers of atoms slide easily over one another. Since graphite does not form bonds with the metal surfaces, it is easily lost: mixing the graphite in base oils makes it possible to lower the friction level beyond the level achievable by the oils alone, and the oils act as carriers, or as a medium to contain the graphite.

Other lubricating techniques are used to separate rubbing surfaces, such as teflon coatings, which act as dry lubricants to minimize friction and the drag caused by liquid lubricants. The techniques are different, but the goals are the same: to separate rubbing surfaces and to minimize friction.

Synthetic lubricants are manufactured for specific purposes. These lubricants are not blended from natural oils, but rather produced artificially under controlled conditions to minimize levels of contaminants. By having more control over what goes into a lubricant product, chemical engineers hope to produce a superior lubricant: ideally, they want a thinner lubricant with a higher boiling point (and therefore low evaporation rate), no thermal breakdown of the oil molecules, and with higher lubricity (a measure of the extent to which friction is reduced).

Before the advent of the automobile, petroleum was used mainly for manufacturing kerosene for lamps. Most oil products were obtained from animal, plant and fish oils and fats. These natural oils tend to contain mainly alkenes (unsaturated hydrocarbons), so they differ with their alkane counterparts in that they have lower melting points: the same lubricity could be achieved with a thinner oil, assuming both oils being compared had the same number of carbon atoms. However, these oils tend to have fatty acids that must be neutralized. Alkenes are not as stable as alkanes, so they are more easily oxidized into fatty acids and they become more unstable when subjected to heat. These oils are not hostile to bacteria, which accelerate the deterioration of the oils, whereas mineral and synthetic oils have longer life expectancies. Fatty acids tend to corrode metal parts and also to result in the formation of sludge. Oils and greases for clocks and watches were (and many still are) made from fish oils, whale fat and porpoise oils being among the favourites. The new oils have additives that protect the oils from bacteria and oxidation,

thereby extending their life expectancies considerably. The principles by which lubrication takes place are the same, as outlined above. Note, however, that even the new natural oils have essentially no tolerance for heat and must therefore not be used where heat is generated (such as electric clock motors). You must use a mineral oil for electric clock motors, such as a single-weight, non-detergent oil.

I hope this essay has made you a better-educated consumer of oils and greases for clocks, electric motors, cars, or anything else. It is only a brief overview of a few aspects of tribology that might be of interest to horologists. Tribology, or the study of lubrication, is a very wide field: the more you know, the more you know you do not know! I prefer petroleum-based mineral oils over any other, especially since the quality of mineral oils has improved to such an extraordinary extent in just the last fifteen years, thanks to the hard work of many chemical engineers! Most mineral oils manufactured and marketed in the United States by well known manufacturers are of very high quality indeed, and a statement that the oil meets government and manufacturer specifications is more reassuring still. However, you still must be cautious when selecting lubricants since some lubricants are poorly engineered and since many will not suit the particular application you wish to apply it to (the same is true of clock oils from your clock suppliers: the fact that it says 'clock oil' on the bottle does not mean that the clock oil you bought is of high quality or that it will provide adequate protection of the second wheel pivots, as it might for the escape wheel pivots). Consider these examples. There is a very expensive clock oil that I have had many problems with because it dries after about a year and a half. It is also very thin: it tends to run too easily when applied to bushings. There is another clock oil (the cheapest) that I have found to work very well: it was still liquid five years after I applied it to numerous clocks. Two of my suppliers told me that it is not a clock oil (even though it said 'clock oil' on the bottle) but rather a light machine oil: in other words, a highly refined mineral oil, similar to kerosene in appearance, consistency and smell. The only problem I have experienced with this oil is that it is too thin (at room temperature, here in Texas) and runs too easily when applied to clock bushings (but it has worked very well on my pocket watches). I have had disappointing experiences with three synthetic lubricants and therefore do not use them.

Now for the disclaimer to keep me out of trouble:

1. To lubricate a clock, use only an oil that says 'clock oil' on the bottle.
2. To lubricate an electric clock motor, use only an oil that says 'oil for electric motors' on the bottle.
3. To lubricate a watch, use only an oil that says 'watch oil' on the bottle.
4. To lubricate your car, use only an oil that says 'car oil' on the bottle.
5. Experiment at your own risk!

Mark Headrick