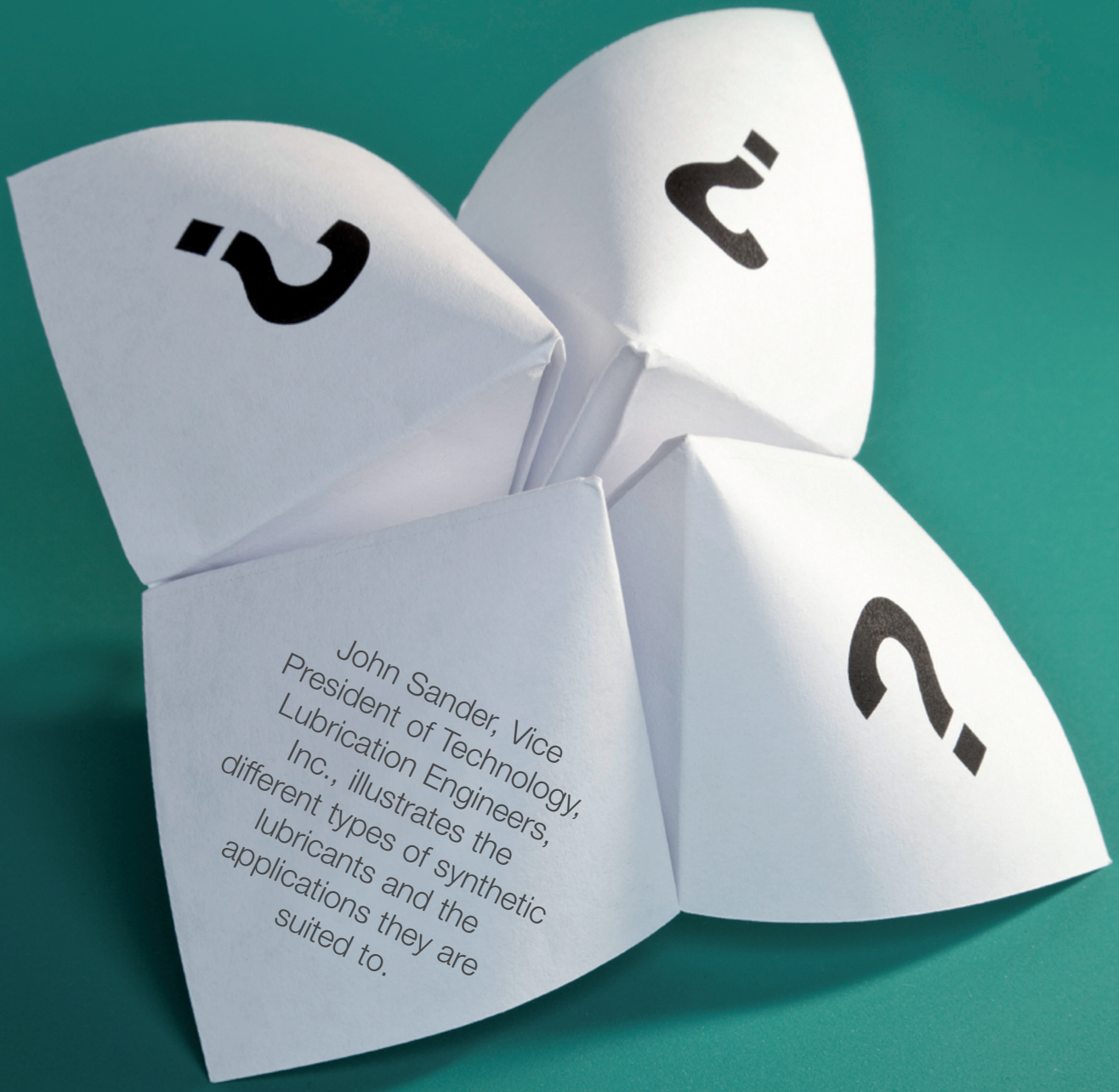
When Do Synthetic Lubricants Make Sense?

Summary

The use of synthetic lubricants in various industrial and automotive applications is becoming more and more common, due in part to heavy marketing of synthetics. The word "synthetic" has become nearly synonymous with high quality or high performance. However, it should not be a given that a synthetic formulation is always the right choice. Those responsible for choosing lubricants have to decide between synthetic and mineral oil based lubricants, and – if a synthetic is the right choice – they have to decide what type of synthetic lubricant to use. This decision can impact the health and longevity of the machinery, as well as an organisation's operational costs and eventually the bottom line. Base fluid type should not be the only consideration. Additional factors that should be considered in the lubricant decision-making process include environment, equipment type, application technique, speed, load, temperature and OEM recommendations.



Introduction

One of the most common questions asked by lubricant users is, "Should I use a synthetic or mineral oil?" This seems like an easy question to answer, but answering it can actually be very complex. Before answering it, it is imperative that you first know exactly what piece of equipment it is that needs to be lubricated.

Lubricants are categorised in a variety of ways. They are almost always categorised first by the application in which they are supposed to be used: for example, engine oil, hydraulic oil, wire rope lubricant, electric motor grease, etc. Users already know where they intend to use the lubricant.

It is when it comes to the secondary categorical selection they have to make that it becomes confusing. Often, lubricants are categorised next by a description of their chemical composition. Specifically, they are described as mineral oil, synthetic or bio-based fluid. Lubricant marketers use descriptions such as full synthetic, 100% synthetic, partial synthetic, para-synthetic, synthetic blend, and other derivations. The term synthetic is probably one of the most overused in the lubricant industry. Over the years, this term has become synonymous with high-performance, and hence high-value lubricants. While this can be true, it can also be misleading.

Philosophically, it is interesting that synthetic lubricants are considered better than nonsynthetic (or natural) lubricants. When it comes to anything other than lubricants – such as foods and beverages – the opposite is true; anything natural is better than synthetic (or artificial). In both examples, the truth is not always that black and white. In a *Machinery Lubrication* article, Scott Schwindaman, president and CEO of Lubrication Engineers, Inc., compared synthetic lubricants to nonsynthetic lubricants:

> "While the trend is intended to promote improved lubrication from the user's standpoint, he or she can be misled in the idea that a synthetic-based lubricant will always provide superior performance. To help the end user choose the right path, he or she must be informed of how the different types of lubricants are formulated with respect to performance in the application."[1]

This point was reiterated by David Whitby in an article in *Tribology and Lubrication Technology* (TLT):

> "The key point is that an engine, compressor, or gear box does not know how an oil was manufactured, just whether it does the job of lubrication. That is whether it has the required level of performance, not whether it is synthetic or mineral oil-based. Using the wrong oil for an application risks equipment damage and significant financial penalties."[2]

So far, this discussion has made lubricant choice seem relatively simple. "Do I choose a mineral oil or a synthetic for my application?" However, the term synthetic is actually a broad term used to describe multiple categories of lubricants. This paper will provide an overview of the three broad chemical category types of lubricants. Then, it will define synthetic lubricants and briefly describe the major types, including their general applications, benefits and disadvantages. The intent is to help alleviate some of the confusion for lubricant end users as they select lubricants for their equipment.

Table 1. API base stock categories

Group	Sulfur, mass %	Saturates, mass %	Viscosity index
I	>0.03	<90	≥80 to <120
II	≤0.03	≥90	≥80 to <120
III	≤0.03	≥90	≥120
IV	All polyalphaolefins (PAOs)		
V	All stocks not included in Groups I – IV		

Lubricant categorisation

Automotive industrial

In general, there are two major lubricant categories: automotive and industrial. These two distinctions are really more important to the lubricant manufacturers and marketers than they are to end users. As the names suggest, lubricants are categorised broadly as dedicated to automotive (transportation) applications or industrial (factory) applications.

Application or equipment

Secondarily, lubricants are usually categorised by the application or piece of equipment in which they are to be used, although it is not unusual for there to be some crossover. Some of the main automotive application categories include engine oils, chassis lubricants, transmission fluids, brake fluids, steering fluids and differential fluids. Some of the main industrial lubricant application categories include metal forming and cutting fluids, hydraulic fluids, electric motor grease, gear oils, compressor oils, chain lubricants, turbine oils and wire rope lubricants.

Base fluid or additive chemistry

Each of the application groups are then subcategorised by base fluid and additive chemistry. Broadly stated, the chemistry of a lubricant is composed of base fluids and additives. The three main types of base fluids are bio-based fluids, mineral oils and synthetics. Most lubricant formulations consist of anywhere from 75 to 99% base fluid. Because of this, it becomes obvious where the categorisation of the lubricant comes from; it is a description of the base fluid chemistry used in the lubricant formula. In general, many lubricant end users are familiar with buying engine oil for their personal vehicles. Bio-based lubricants have not gained popular acceptance for use with engine oils, so most end users generally ask the question upon which this paper is based, "Synthetic or mineral oil?"

Bio-based lubricants were probably the earliest lubricants. They are derived from either animal or vegetable sources. Mineral oils are refined from crude petroleum oil removed from subsurface rock strata and probably constitute the largest category of lubricant base fluid by volume. Synthetics are the main focus of this paper. Although they are growing rapidly in popularity, they are still the subject of much debate – even among lubrication experts.

In addition to base fluids, the other major chemical constituents of lubricants are the additives. Additive descriptions used to categorise lubricants are based upon certain performance properties that the additives impart upon the lubricant formula. While they will not be discussed in detail in this article, a few of those used to categorise lubricants are unadditised, rust and oxidation (R&O), anti-wear (AW), extreme pressure (EP), detergent inhibitor (DI) and dispersant.

Technical base fluid categorisation

To categorise lubricant base fluids, the American Petroleum Institute devised a standardised system as part of the API

Publication 1509 *Engine Oil Licensing and Certification System* (Table 1).[3]

The API originally created its system to describe engine oil base fluids, but now it is finding acceptance in describing the base fluid chemistries used in other lubricant categories as well.

Groups I – III are derived from petroleum crude oil. Each successive group number represents a higher degree of refinery processing. Group IV is for polyalphaolefin synthetic fluids and Group V is a catchall for all other synthetics and the bio-based fluids. Groups III – V are generally marketed as synthetics. This is where the lubricant industry definition of a synthetic controversy begins. The next section will provide authoritative definitions of a synthetic lubricant.

What is a synthetic?

Definitions

To provide clarification, it is often useful to see how those considered to be the authorities define terms. One authority defined synthetic as: "of, relating to, or produced by chemical or biochemical synthesis."[4]

Another source defined synthesis as, "the combination of two or more parts, whether by design or by natural processes. Furthermore, it may imply being prepared or made artificially, in contrast to naturally."[5]

A better definition that brings both of these together is, "noting or pertaining to compounds formed through a chemical process by human agency, as opposed to those of natural origin."[6]

Maybe one of the best ways to explain synthesis is to use an analogy. Many remember playing with Lego® building blocks as a child. Various small blocks are connected together to make a larger structure. In general, this is what synthetic base fluid manufacturers do as they manufacture their fluids. They react two or more small chemical "blocks" until they build the desired combined structure.

Controversy

This limited synthetic description was challenged several years ago in an "advertising court" case, and now the accepted definition has been expanded to include another route to synthesis. Let's again return to the building block analogy. After the blocks had been played with and dumped into a storage container, there was a mixture of blocks already stuck together. These chunks of blocks could be dismantled and put back together in an entirely new structure. In the same way, refined crude petroleum oil has traditionally been used to produce mineral oil, but now some crude oil can be very highly refined and then used to create new formulas. This is an example of the second type of synthesis.

The case that led to this new broader definition of synthetics was in 2000, when the U.S. division of Mobil Lubricants appealed to the National Advertising Division (NAD) of the US Council of the Better Business Bureau to dispute the use of the word "synthetic" by Castrol on its Syntec brand of engine oil as being misleading.[2]

Castrol Syntec engine oil contained a chemically modified mineral oil. Mobil, with its own synthetic engine oils based on polyalphaolefin base fluids, argued that Castrol's Syntec brand oils were not synthetic. The NAD sided with Castrol, determining that chemically modified mineral oils are so heavily processed that they are no longer mineral oil, but instead synthetic. However, some experts did not agree with this ruling. For example, Stephen Godfree, editor of the *Journal of Synthetic Lubrication*, in 2000 wrote a publisher's note in which he expressed his dissatisfaction with this ruling. "The first thing to realise is that the NAD is a powerless entity outside the USA. Its jurisdiction is advertising claims on its home territory. It would not be unreasonable to say that it was out of its depth here …"[7]

Despite Godfree's opinion and those of others who agree with him, there are marketers worldwide selling various types of products and calling them synthetic, and they are supported by the outcome of this case.

Types of synthetic base fluids

The synthetic chemical categorisation of lubricants includes numerous base fluid types. In fact, whole books have been written on this subject, including *Synthetics, Mineral Oils, and Bio-Based Lubricants Chemistry and Technology*, edited by Leslie Rudnick.[8]

Table 2 is a brief explanation of some of the more commonly used synthetic base fluids. These include chemically modified mineral oils, polyalphaolefins (PAOs), polyisobutylenes (PIBs), esters, polyalkylene glycols (PAGs), phosphate esters, silicones, alkyl benzenes, alkylated napthalenes, and fluorinated polyethers.

The most commonly used synthetic lubricant base fluids in the list above are the chemically modified Group III mineral oils and PAOs. All of the rest could be described as specialty synthetics, as they tend to be used in specific applications that are not compatible with mineral oils. Following are a few additional comments about each of the synthetic lubricant base fluid types.

Chemically modified group III mineral oils and polyalphaolefins

Of all of the synthetic base fluid types, chemically modified mineral oils and PAOs share the largest volume. These base fluids are often used interchangeably. In fact, their performance in engine oils has been found to be very similar. Both have good oxidation resistance because they have highly saturated paraffinic chemical structure (there are not a lot of places for oxygen in the air to react with them and break them down). Because PAOs are built by combining small molecules, the range of viscosity for PAOs is broader.

Also, PAOs provide superior performance for extreme temperature applications. In very low-temperature applications, the chemically modified mineral oils still contain low levels of paraffin wax. Therefore, PAOs can continue to pour to lower temperatures. Although chemically modified mineral oils have very good oxidation stability, they can still have some molecular double bonds and branches that are not in PAOs. These improvements come at a cost, however, with PAOs currently costing nearly 50% more than chemically modified oils. Also, in some applications, such as engine oils, the fluid must be changed due to contamination before fluid wears out due to oxidation. The question that must be asked is whether actual value can be realised by the end user that will justify paying for the extra performance.

Polyisobutylenes

In general, the PIB viscosity increases as the polymer chain size increases. Along with this, the stickiness of the material increases. Thus, PIBs are often used as viscosity modifying additives for

other base fluids that are not easily produced at a high viscosity. Over the years, mineral oil refiners have increased the use of a refining technology called hydroprocessing. Hydroprocessing results in elimination of high viscosity mineral oil fractions commonly used in gear oils, called brite stocks. Because they are compatible with mineral oils and PAOs, PIBs have been one of the main brite stock replacements. Because of their stickiness, another common use of PIBs is for synthetic open gear applications and wire rope coating lubricants.

Polyalkylene glycols

While Table 2 notes that PAGs have compatibility challenges with some paints, seals and other lubricants, they are actually a very flexible and effective synthetic base fluid type. Once installed, they have been shown to provide high performance under various challenging conditions, such as very high and low temperatures and in combination with water for fire-resistant hydraulic fluid applications. The main challenge in any application is converting from a nonpolar lubricant, such as mineral oil or PAO, to a PAG. Because of the incompatibility of these fluid types, it can result in the formation of a gel when converting equipment either from or to PAG products. PAG producers have been aware of this and it has caused one producer to develop what it has coined as oil soluble PAG.[9]

Esters

Just as categorising a lubricant as synthetic is too broad, the same is true with categorising a synthetic lubricant as an ester. Various types of esters are used as synthetic lubricants, including diesters, monoesters, phthalates, trimellitates/pyromellitates and polyol esters. While all contain a similar chemical structure, there are chemical variances in the entire molecule that provide differences in the performance. One lubricant company's ester-based synthetic lubricant may not be the same as another company's, and for that reason, it is a good idea to ask compatibility and performance questions of the lubricant marketer prior to making the lubricant change to or from an ester-based synthetic lubricant.

Because of the varying functional groups attached to the ester group in the ester molecular structure, some esters are used along with very nonpolar fluids, such as PAOs and chemically modified mineral oils, to improve the solubility of polar additives. Also, certain esters have been found to promote slight seal swelling; thus, they can be used as additives to lubricant base fluids that cause seal hardening to offset the hardening affect.

Phosphate esters

While there are PAGs and esters that are also formulated, branded and sold as fire-resistant hydraulic fluids, the marketers of phosphate esters have designated themselves as the only suppliers of truly fire-resistant hydraulic fluids. This is the main application for these types of synthetic fluids. What they mean by this is that they will not even propagate a flame in the flame extension test used to qualify a lubricant as a fire-resistant hydraulic fluid. The competitive fluids will actually propagate a flame, but the instant the flame source is removed, the flame is immediately extinguished. While phosphate esters are extremely efficient as fire-resistant hydraulic fluids, fluid contamination control is even more important with them than most other lubricant base fluids. Water contamination is one of the most common problems, and it can dramatically decrease the life of these fluids as well as potentially create corrosion issues inside the machinery.

Silicone fluids

It is interesting to note that both phosphate esters and silicone fluids can be used at low concentrations in other lubricant formulations as additives. However, above a few parts per million, silicone fluids are insoluble in almost all other lubricant types. The US Food and Drug Administration has approved certain silicone fluids for direct and indirect contact with food and for lubrication of surgical equipment. They have been found to be oxidation and radiation-resistant, and have found use in medical and food processing related industries. They are relatively expensive and would be described as a specialty synthetic lubricant.

Alkyl benzenes/alkylated naphthalenes

Certain fluids have been described as additive blend fluids, such as the PIBs, esters, phosphate esters and silicones. Because of the aromatic chemical structure of alkyl benzenes and alkylated naphthalenes, they have also found use as additives in other base fluids to overcome solubility challenges. As they age, nonpolar fluids, such as PAOs and chemically modified mineral oils, have been found to be less capable of managing contamination, such as oxidation residues and water contamination. Oxidative degradation can result in the formation of varnishes and sludge that cause equipment operability issues. Alkylated benzenes and alkylated naphthalenes have been shown to have very good thermal and oxidative stability (possibly because their molecular structure is similar to some commonly used lubricant antioxidant additives). As a result, they are beginning to find increased use as the sole base fluid in some high-temperature lubricant and heat transfer applications.

Fluorinated polyethers

Certain applications are required to operate under such extreme conditions that even certain synthetic lubricants are not sufficient. As their name would suggest, these fluids contain fluorine as part of their chemical structure. This makes them very inert to react with other chemicals. For example, when a piece of equipment is operating in a pure oxygen atmosphere, almost every lubricant type mentioned thus far can become reactive. In fact, chemically modified mineral oils and PAOs – synthetic lubricants known to have good oxidation stability – will react so vigorously with oxygen that they will catch fire. These base fluids can be mixed with fluorinated or silicon-based thickeners to produce nonreactive greases as well. Unfortunately, fluorinated polyethers are very expensive and are reserved for applications operating at very high temperatures, in oxidative environments or in chemically reactive applications where an inert lubricant is required.

Conclusion

A quick review of Table 2 shows why it is insufficient to categorise a lubricant solely as a mineral oil or synthetic. There are just way too many types of synthetics. Hopefully, this article has provided some of the differences between the types of synthetic fluids, and reduced the confusion for lubricant end users who are trying to answer the question,

"When do synthetic lubricants make sense?". In most cases, the end user should not have to be concerned with all of these details. A technically astute lubricant supplier should be able to provide the proper technical support to help the user systematically answer all of the questions related to the application. Often the question of whether it is mineral oil or synthetic is not enough. The first steps are to review the equipment manual and contact a dependable lubricant supplier.

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Table 2. Synthetic lubricant types

Type	Typical applications	Advantages	Disadvantages
Chemically modified group III mineral oil	Engine oil, compressor oils, automatic transmission fluid	Good oxidation stability, near PAO performance with lower price tag	Limited to low-viscosity grades, low-temp performance not as good as some other synthetics
Polyalphaolefin (PAO)	Engine oil, hydraulic fluids, gear oils, greases, automatic transmission fluids, compressor oils, pumps, metalworking fluids	Wide operating temp range – good VI, shear stability, compatible with mineral oils, not corrosive, thermally stable, low toxicity, food grade	Additive solubility limited, some seal shrinkage
Polyisobutylene (PIB)	Anti-misting additive, two-stroke engine oils, marine cylinder lubricants, grease, gear oils, wire rope lubricants, metalworking fluids	Very wide viscosity grade selection, can be sticky, brite stock replacement, food-grade, separate from water, low residue forming at high temps, low toxicity	Higher viscosity grades very sticky, depolymerise above 200 °C (can be beneficial)
Polyalkylene glycol (PAG)	Refrigeration fluid, gear lubricant; chain lubricant, fire-resistant hydraulic fluids, compressor lubricants, metalworking lubricants, textile lubricants	High viscosity index, good temp stability, excellent lubricity, water soluble, food grade, low toxicity	Compatibility challenges with paint and seals, nonpolar lubricants, water soluble, challenging to additise, not compatible with mineral oil or most other synthetics
Esters	Refrigeration fluids, high-temp chain lubricants, biodegradable hydraulic, aviation turbines, gear oils, air compressors, metalworking fluids, greases, vacuum pumps	Numerous types (flexibility), good solvency, most biodegradable, high flash points, low vapour pressure – volatiles, thermally stable, lubricity	Numerous types (confusion), hydrolytically instable, hygroscopic, limited seal and paint compatibility (swells and softens)
Phosphate esters	Fire-resistant hydraulic fluid, aviation hydraulic fluid	Fire resistant, thermal stability, oxidative stability, very high boiling points, excellent lubricity	Hydrolysis, hygroscopic, become corrosive if hydrolysed, can contain extremely low levels of neurotoxins, 3 – 5 times cost of mineral oil hydraulic fluids
Silicones	Plastic parts, greases, medical lubricants	Oxidation resistant, USP/food grade	Limited additives, poor lubricity in ferrous metal contacts, affect adhesion of paint on metal surfaces, expensive
Alkyl benzenes, alkylated napthalenes	Refrigeration fluids, grease, extreme low-temp hydraulic fluids, blend stock for use in Group III – V products	Good solvency, oxidative stability, thermal stability, hydrolytic stability, solvency and dispersancy, very low pour points	Besides very low pour point, performance similar to mineral oils except 3 – 5 times the cost
Fluorinated polyethers	Seal for life motor bearings, lubrication of equipment in chemically reactive environments, extreme high-temp greases	Useful in oxygen environments, chemical resistant, thermal, oxidative and hydrolytic stability, shear stable, not flammable, radiation resistant	Very expensive, poor additive solubility, not compatible with mineral oil