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The Basics of Rotary Screw Compressor Lubricants

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Lubricant is a critical component in rotary screw compressors. Understanding the characteristics of lubricant types helps ensure their proper application and increases customer satisfaction by extending the service life of compressors. Below we discuss the types of lubricants and then discuss factors that reduce the effectiveness of lubricants and cause premature wear or damage in rotary screw compressors.

Types

There are seven basic types of lubricants used in compressors today. Each type of lubricant has advantages and disadvantages for specific applications.

These are:

1. Mineral oils
2. Synthetic hydrocarbons
3. Organic esters
4. Phosphate esters
5. Polyglycols
6. Silicones
7. Blends (Semi-synthetics)

FIGURE 1: there are seven basic types of lubricants used in compressors today.

Mineral Oils

Mineral oils (petroleum oils) have long been used in various types of compressors. Their use in rotary screw compressors was common until the 1980's. Some manufacturers' factory filled with motor oil and some used automatic transmission fluid. Mineral oils began to lose favor when oil recyclers began to charge for oil disposal. With oil change intervals as low as every 1000 hours, many manufacturing plants had to change eight times per year.

An advantage of frequent oil changes is that contaminants in the compressor are removed with the waste oil. In highly contaminated environments, mineral oil is still used for this reason. Mineral oils have the disadvantage of a complex mix of natural hydrocarbon molecules. There are waxes that solidify at low temperatures, volatile components that vaporize and natural mineral oils tend to oxidize quickly, forming varnish and sludge, when exposed to high temperatures and elevated pressures.

Synthetic Hydrocarbons

Synthetic hydrocarbon lubricants are engineered for particular applications. For compressor applications, polyalphaolefin (PAO) base stock is most commonly used. PAOs provide many of the best lubricating features of a mineral oil without the drawbacks. Although PAO components are derived from petroleum base stock, they are chemically re-engineered to have a consistent, controlled molecular structure of fully saturated hydrogen and carbon.

Because their molecular structure is homogeneous, their properties and characteristics are predictable. PAOs separate from water extremely well, are chemically stable and have low toxicity. PAOs, however, are not good solvents. The additive chemistry must be adjusted for that fact. Additive packages in PAO lubricants are usually blended to beyond their saturation point at cool temperatures. Under the normal operating conditions of compressors, this is not a problem. The elevated temperature and constant motion keep the additives dissolved.

When PAO lubricants are stored for prolonged periods of time, it is possible for some of the additives to condense and cause the lubricant to have pockets of cloudiness in the storage container. These additives will return to solution with a bit of agitation/stirring. In a paper presented to an engineering meeting in Sweden several years ago, a major bearing manufacturer shared results of their testing of lubricants for use in rotary screw compressors. Their conclusion was that PAO lubricants were the best lubricants for rolling element bearings used in screw compressors.

Pure PAO fluids have a tendency to cause certain low nitrile Buna-N elastomers and some other synthetic materials to become brittle and crack. For compressor applications, a small amount of ester fluid is usually blended in the mix to counter this tendency. The ester also helps keep additives in solution.

Organic Esters

The next class of synthetics is the organic esters. The two primary types used in compressors are dibasic acid and polyol. Dibasic acid lubricants are better known as diesters. Diesters were the most popular synthetic lubricants when synthetic lubricants first became common in compressor applications in the 1970's and 1980's. They have a number of desirable qualities for compressor applications. They have a stable viscosity over a wide temperature range, high film strength, good metal wetting characteristics and a low vapor pressure at high temperatures.

Diesters are strong solvents. As such, they readily accept additives, making them customizable for particular applications. Being a strong solvent, however, is also one of their primary drawbacks. Diesters will dissolve paint and varnish, cause certain common elastomers to swell and deteriorate and can damage some common downstream components of compressed air distribution systems. Esters can react with water to form corrosive acids and volatile alcohols.

Diesters are not commonly used in rotary screw compressors today, but still enjoy wide popularity among large reciprocating compressor users where the diesters' solvency and resistance to carbon formation is a plus for extended valve life. Polyol esters have similar characteristics to diesters but have the added advantage of being stable at higher temperatures and oxygen concentrations. Although the primary market for polyol esters has been for use in turbines, these fluids are being used in some high-pressure rotary screw applications.

Phosphate Esters

Phosphate esters have very limited application. Phosphate esters have a poor viscosity index, poor tolerance of heat and moisture, and become corrosive as they degrade. For that reason, service life is very limited and fluid changes are required often. They can, however, be made fire resistant, and once ignited, they will only continue to burn if the source of ignition remains present. Petro-chemical plants, refineries and other high-risk facilities form the primary market for this type of lubricant.

Polyglycols

Polyglycol fluids, sometimes called PAG fluids (polyalkylene glycol), were first developed for natural gas compressors. They can be manufactured from either of two primary chemical stocks, or a blend of these stocks. Propylene oxide has the characteristic of being hydrocarbon soluble and water insoluble. Ethylene oxide has opposite characteristics, being water-soluble and hydrocarbon insoluble. With a gas analysis, blenders can adjust the amount of each type to produce a final product with the correct characteristics required by an individual application. The solubility differences in the two basic fluids make the chemistry of the additive package very important. For natural gas applications, the fluids are blended so they are not diluted by the particular hydrocarbon gas being compressed.

Polyglycol fluids for use in air compressors are compromise fluids. They were developed to reduce complaints about poor lubricant life and varnish deposits. The formation of varnish is an indication of a petroleum or synthetic hydrocarbon lubricant that has failed. Since polyglycols do not form varnish, there is no visual indication that the lubricant has failed. Polyglycols attract water and mix readily. This characteristic makes separation from condensate difficult and reduces their ability to protect bearings. The saturation point for these lubricants is much higher than for mineral or synthetic hydrocarbon fluids, but water entrained in the fluid beyond this point will separate into free water.

Silicones

Silicone fluids have been available for many years. They have excellent resistance to heat, oxidation and vaporization. Being chemically inert, they can be used in applications where exposure to oxidizing agents is possible. High cost, leakage, and poor lubricating properties limit their proper use to applications requiring their unique chemical characteristics. Further, there are many applications that require a silicone-free system, painting is one example, and silicone lubricants should be avoided.

Blends (Semi-Synthetics)

Virtually all synthetic fluids, except silicones, are actually blends of base stocks and additives engineered to provide the desired characteristics. When a fluid is referred to as a semi-synthetic, it is usually a blend of a synthetic stock, usually a PAO, and most likely a Group I or Group II mineral oil. The goal of most blends is to provide many of the benefits of a pure synthetic at a lower cost. A good application for a blended fluid is one where contamination in the ambient air necessitates more frequent lubricant changes.

Note: Food grade lubricants are usually either PAO-based or tech white mineral oil based with a very limited additive package. This limited additive package results in a significantly reduced service life when compared to non-food grade versions of the same lubricant.

Causes of bearing damage in rotary screw compressors

Water

The most common and most damaging contaminant in rotary screw compressors and rotary screw vacuum pumps is water. The primary source of water contamination in rotary screw compressors is the inlet air. Ambient humidity and the compressors operating conditions affect water formation in the lubricant circuit. A major bearing manufacturer has stated, “It is well known that free water in lubricating oil decreases the life of rolling element bearings by ten to more than one hundred times…”. When bearing life calculations are made, the assumption is that the lubricant contains 65 to 100 ppm of water. This is a normal amount of water that can be expected to be present in new PAO lubricant. An increase to 300 ppm will result in an actual bearing life of about half the calculated life. Water content of 1000 ppm or more is not uncommon in operating compressors.

Water can be present in a compressors’ lubricant circuit in both a dissolved state and a free state. Lubricants, like air, have a saturation point. Depending on the type of lubricant, a certain amount of water will be dissolved in the fluid. Once the lubricant reaches its saturation point, additional water will condense to form free water. The extreme examples are pure PAO base stocks that have non-polar molecules and polyglycol lubricants that have highly polarized molecules. PAO lubricants are sometimes described as being hydrophobic because they do not easily combine with water, reaching their room temperature saturation point at just over 100 ppm.

PAO lubricants separate from water readily so the free water can be easily drained from the compressor. Polyglycol lubricants, on the other hand, are sometimes described as hygroscopic. They combine readily with water and can be found with as much as one percent of their volume as water molecules (10,000 ppm).

Rolling element bearings, like those used in rotary screw compressors, rely on elastohydrodynamic lubrication. That means that the elements ride on a film of lubricant as they roll across the race. Lubricants are formulated to have sufficient film strength to prevent contact between the elements and the race. The viscosity of lubricants increases as pressure increases. Under the extreme conditions found in bearing lubrication, the lubricant can momentarily become a solid. Water, however, does not increase in viscosity as pressure increases. Dissolved water can weaken the film strength of some lubricants and free water has no effective film strength in this type of application. As a roller or ball encounters water, there is insufficient film strength to prevent the element from contacting the race. This contact, under conditions of extreme pressure, can cause micro-fractures. Continued exposure to water can also cause a condition known as hydrogen embrittlement, increasing the formation of micro-fractures. This will continue until small flakes of the bearing surface begin to break away. This debris moving through the bearing will cause additional damage and lead to the failure of the bearing.

When standard petroleum oils were used in rotary screw compressors, the accumulated water was removed when the oil was changed about every six weeks (1000 hours). With extended life synthetic lubricants, water may accumulate for 8000 hours if it is not drained from the separator reservoir periodically. Without regular monitoring, significant amounts of water can collect in the lubrication circuit and reduced bearing life can be expected.

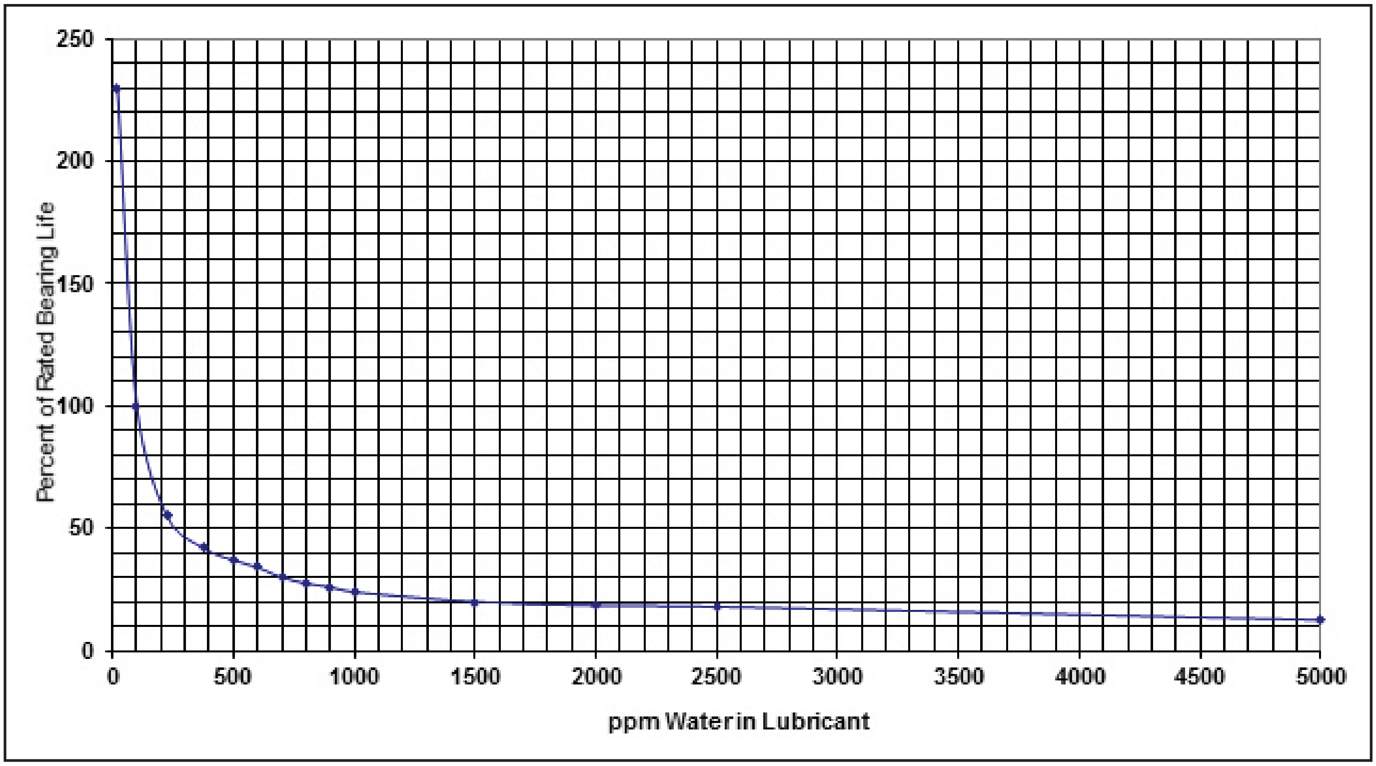

CHART 1: Effect of water on rolling element life

Particulate

Second to water, the most common contaminant is particulate. In operation, rolling element bearings ride on a film of lubricant that is from 0.1 to 1.0 micron thick. Any particulate larger than that can cause damage to the bearing. Filtering to one tenth of a micron is impractical for most applications. Even filtering to one micron is difficult. Most bearing manufacturers take this into account when calculating L10 bearing life. They use the assumption that the lubricant will meet the ISO Base-Cleanliness Target for rolling element bearings.

Fluid cleanliness rated per the ISO Code is reported as a three-number rating such as 18/16/13. The first number (in this example, 18) represents the number of particles per milliliter (about an eyedropper full) of fluid that were greater than or equal to 4 microns. The second number represents the number of particles that were greater than or equal to 6 microns. The last number represents the number of particles that were greater than or equal to 14 microns. In the above example, there would be between 1300 and 2500 particles greater than or equal to 4 microns, 320 to 640 particles greater than or equal to 6 microns, and 40 to 80 particles greater than or equal to 14 microns. Each increase in rating number represents an approximate doubling of the number of particulates. The ISO Base-Cleanliness Target for new fluid for rolling element bearing lubrication is 16/14/12.

Most analysis programs report only a two-number rating. This two-number reporting is either based on an older (pre-1999) reporting method that counted 5 and 15 micron particles or simply the last two numbers of the three-number system. There is a slight difference between the 5 and 15 micron rating and the 6 and 14 micron rating of the newer system, but the practical results are similar. In other words, the ISO Base-Cleanliness Target for new fluid for rolling element bearing lubrication, which is 16/14/12, could also be reported as 14/12.

Knowing the average ISO 4406 numbers for a particular compressor over an extended period of time will allow estimation of the particulate contamination's effect on bearing life. The following chart can be used to make a quick estimate.

ISO CODE	MINIMUM	MAXIMUM
1	0.01	0.02
2	0.02	0.04
3	0.04	0.08
4	0.08	0.16
5	0.16	0.32
6	0.32	0.64
7	0.64	1.3
8	1.3	2.5
9	2.5	5.0
10	5.0	10.0
11	10.0	20.0
12	20.0	40.0
13	40.0	80.0
14	80.0	160
15	160	320
16	320	640
17	640	1,300
18	1,300	2,500
19	2,500	5,000
20	5,000	10,000
21	10,000	20,000
22	20,000	40,000
23	40,000	80,000
24	80,000	160,000
25	160,000	320,000
26	320,000	640,000
27	640,000	1,300,000

TABLE 1: ISO 4406: 1999 Fluid cleanliness Codes. Number of Particles per 1 ml of fluid.

Using this chart is simple. If the analysis report stated the ISO 4066 as 21/18, for example, cleaning the lubricant to the point that the rating improved to 15/12 would increase the expected bearing life 300%. Another way to look at this is that the lubricant started at 15/12 and is now 21/18. At 21/18 the expected lubricant life is only one third of what it would be at 15/12.

The primary source of particulate contamination in rotary screw compressors is the inlet air. Dirt and dust making their way through the inlet filter will show in lubricant sample tests as silicon (or silica) and possibly aluminum. While dirt and dust can have different elemental constituents, including magnesium and calcium, silicon oxides and aluminum oxides are the most common.

The presence of barium, boron, molybdenum, phosphorous, and zinc in an oil sample are of less concern because they are common additives to lubricants (though increased levels of zinc and copper in subsequent samples could indicate wear conditions of brass components). If these elements are found in a sample, where they were not present in prior samples, it could indicate that the lubricant was contaminated with another type of fluid. If these elements are found in the first sample, but are not in the original lubricant formula, it could indicate a contaminated transfer pump. It is important to remember that the additive package in one lubricant may react with the additive package in another lubricant. For this reason, do not mix brands of lubricant. This may lead to the premature failure of the fluid.

Note: Chromium, cobalt, copper, magnesium, manganese, nickel and iron particulates in an oil sample are indicative of metal wear.

Additive depletion is also accelerated by the presence of water and wear particles. Many of the additives consist of polar molecules. This makes them attracted to solid surfaces such as internal metal components. Some additives are specifically designed for this so they will combine with metal contaminants, making them easier to filter out of the lubricant system. Other (anti-corrosion) additives will adhere to internal metal surfaces to prevent corrosion.

Bearing Life Factor

Current Machine Cleanliness (ISO 4406)	2x	3x	4x	5x	6x	7x	8x	9x	10x
26/23	22/19	20/17	18/15	17/14	16/13	15/12	15/12	14/11	14/11
25/22	21/18	19/16	17/14	16/13	15/12	14/11	14/11	13/10	13/10
24/21	20/17	18/15	17/14	16/13	15/12	14/11	13/10	13/10	12/9
23/20	19/16	17/14	15/12	14/11	13/10	13/10	12/9	11/8	11/8
22/19	18/15	16/13	14/11	13/10	12/9	11/8	11/8	---	---
21/18	17/14	15/12	13/10	12/9	11/8	11/8	---	---	---
20/17	16/13	14/11	13/10	11/8	---	---	---	---	---
19/16	15/12	13/10	11/8	---	---	---	---	---	---
18/15	14/11	12/9	---	---	---	---	---	---	---
17/14	13/10	11/8	---	---	---	---	---	---	---
16/13	12/9	---	---	---	---	---	---	---	---
15/12	11/8	---	---	---	---	---	---	---	---

CHART 2: Bearing Life Factor

Oxidation

Because they are mixed with air at high temperatures under pressure, all air compressor lubricants will oxidize eventually. The oxidation of lubricants produces a number of unwanted effects. As the lubricant begins to oxidize, organic peroxides will form. As the lubricant continues to oxidize, alcohols, ketones, and organic acids will form. These compounds will show as an increase in the Total Acid Number (TAN) on a fluid analysis report. With synthetic hydrocarbon lubricants, an increase in TAN of 1 above the lubricant's base TAN is cause for alarm and a TAN increase of 1.5 indicates a fluid on the verge of failure. Varnish and other unwanted substances quickly follow. With regular mineral oils, this process can begin after only one to two thousand hours in a rotary screw compressor. Synthetic lubricants are more stable than natural mineral oils and oxidize more slowly. Most full synthetics have an 8000-hour service life rating or more.

Note that Food Grade lubricants behave differently! Consult the manufacturer to determine the behavior over time of a specific lubricant.

When PAO synthetics were first introduced, their additive packages were not well engineered. As the anti-oxidant package was depleted and the fluid reached the end of its service life, the lubricant could progress from good to completely polymerized (varnish) in a matter of days. Although newer formulated additive packages have greatly reduced this problem, synthetics should still be changed when they reach their service hour or calendar life, regardless of sample analysis.

Some of the by-products of a lubricant that is very near the end of its useful life will likely remain in the lubrication system after it has been drained. It is very important to remove as much of the old lubricant as possible. The additive package of the new lubricant will react to these by-product as contamination, rapidly depleting the additives in the new lubricant. It is not unusual for the life of fresh lubricant to be reduced to as little as 25% of its expected life when the system is not completely and thoroughly drained and cleaned. For this reason, it is important to remove the fluid while it is still in good condition and not wait until it has started to form these by-products.

Storage, handling and transferring lubricants affect the cleanliness of the fluid. It is very important to use only clean, dedicated containers and transfer pumps. Do not use one pump for several different fluids. Even a small amount of residual fluid in a pump can contaminate an entire sump.

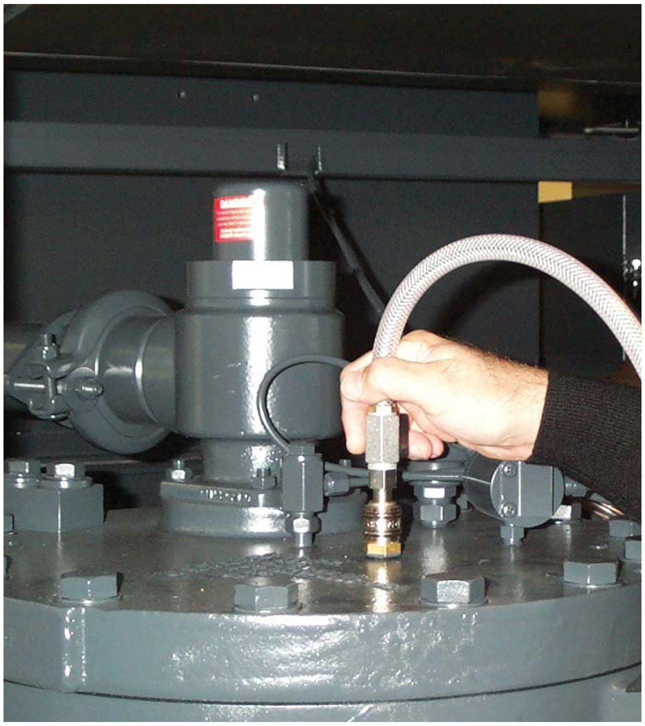

FIGURE 2: proper collection practices are vital in collecting an accurate sample

CONCLUSION

Lubricant is a critical component in rotary screw compressors. Its condition is the key element in determining the service life of the machine, and it is constantly exposed to contamination. In order to maximize the service life of the compressor, follow these rules:

1. Locate the compressor inlet to draw clean, cool air.
2. If the compressor is air-cooled, provide clean, cool air to inlet of the cooling air system. Keep coolers clean.
3. If the compressor is water-cooled, provide clean, cool water to the heat exchanger. Clean or replace the cooler if it becomes fouled. Fouling restricts heat transfer.
4. Sample the lubricant frequently.
5. Stop the compressor once per week and check for water in the separator reservoir. Drain off any water found. In hot and humid environments, this may have to be done more often.
6. Inlet filtration is the first line of defense. Clean the inlet filter often and replace when required. Examine the connection between the filter and the airend for leaks to make certain no ambient air is drawn in behind the filter. Check filter fit for a good seal.
7. Change the lubricant before it gets near the end of its life. Depleted lubricant left in a compressor (even a relatively small amount) can significantly reduce the service life of the new lubricant. If the lubricant has started to fail, use a lubricant flush prior to changing the fluid.
8. Properly apply compressors to avoid low duty cycles, keeping temperatures within their designed operating range.

About the Author

Wayne Perry is Senior Technical Director at Kaeser Compressors, Inc. An industry specialist with more than 30 years of experience in all aspects of the compressed air business, Perry is a Qualified AIRMaster+ Specialist for the U.S. Department of Energy and a former instructor for Compressed Air Challenge. He has provided extensive technical expertise in the development of international standards for compressed air system assessments and has also worked as a Compressed Air Expert for the United Nations Industrial Development Organization. Perry serves on various technical and standards committees of the Compressed Air and Gas Institute. He can be reached at wayne.perry@kaeser.com.

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