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Machine-Dedicated Viscosity and Moisture Analysis by Trico

Trouble-Shooting Viscosity Excursions

NORIA

Machine-Dedicated Viscosity and Moisture Analysis by Trico

By Brad Rake, Trico Mfg. Corp.

Viscosity is not only the most important physical property of a lubricant; it can also be effectively used as a measurement of the overall condition of the oil. Many damaging factors can be monitored by the change in viscosity. The Trico Oil Security System, or OSS, is engineered to detect changes in viscosity online, automatically, without operator involvement (Figure 1). Although it may be difficult to pinpoint the actual source of change, when used as a dedicated device, the OSS can be extremely helpful in preventing damage, especially when used in conjunction with an equipment maintenance program.

Lubrication Film

In order to more fully understand the importance of viscosity, it is necessary to understand how a lubricant works. The primary function of a lubricant is to reduce friction and wear. In order to perform these functions, a protective oil film is required. The three basic oil film conditions are referred to as:

1. **Full Film** - Denotes the presence of enough lubricant to ensure complete separation of the moving surfaces. Also known as hydrodynamic full film.
2. **Elastohydrodynamic** (EHD) - A hydrodynamic film formed by applied pressure or load. Predominantly found in rolling element bearings.
3. **Boundary Layer** - Sometimes referred to as thin film lubrication. Usually the result of insufficient lubricant supply or especially high loads at low speeds. Although lubrication is present, the conditions are insufficient to achieve separation of frictional surfaces.

In rolling element bearings, for instance, the load on a roller causes it to move toward a stationary element, or raceway. This load creates a pressure area that elastically deforms, creating the "Hertzian" contact fatigue zone. This pressure can reach as high as 200,000 psi (13,789 bar) - compressing the lubricant into a thin film. The viscosity of the oil increases where this fluid film acts momentarily as a solid and allows the ball to roll without metal-to-metal contact. When the viscosity is wrong, the load carrying ability of the lubricant is negatively affected (Figure 2). Additionally, if the oil degrades to the point where it is too thick to penetrate between these surfaces, the oil supply may not be adequate to prevent sacrificial (destructive) contact.

Fundamentals of Lubricant Viscosity

The viscosity of a lubricant depends on its temperature, load and physical state. Viscosity has a direct relation to the lubricant's film strength and ability to keep moving parts separated. In applications involving high speeds, low loads and low temperatures, a low viscosity or thin lubricant is a good choice. High viscosity or thick lubricant works better for low speed, high loads and higher temperatures. It is critical to ensure that the viscosity is high enough to provide an effective oil film, but not high enough to create fluid friction due to viscous shear, commonly referred to as churning. Because it is apparent that selecting the right viscosity is critical, it is equally important to maintain the proper viscosity.

Causes of Viscosity Change

Because maintaining the proper viscosity is important, monitoring changes in viscosity would only make sense. After detecting a change in

Figure 1. Monitoring the Lubricant in a Process Pump

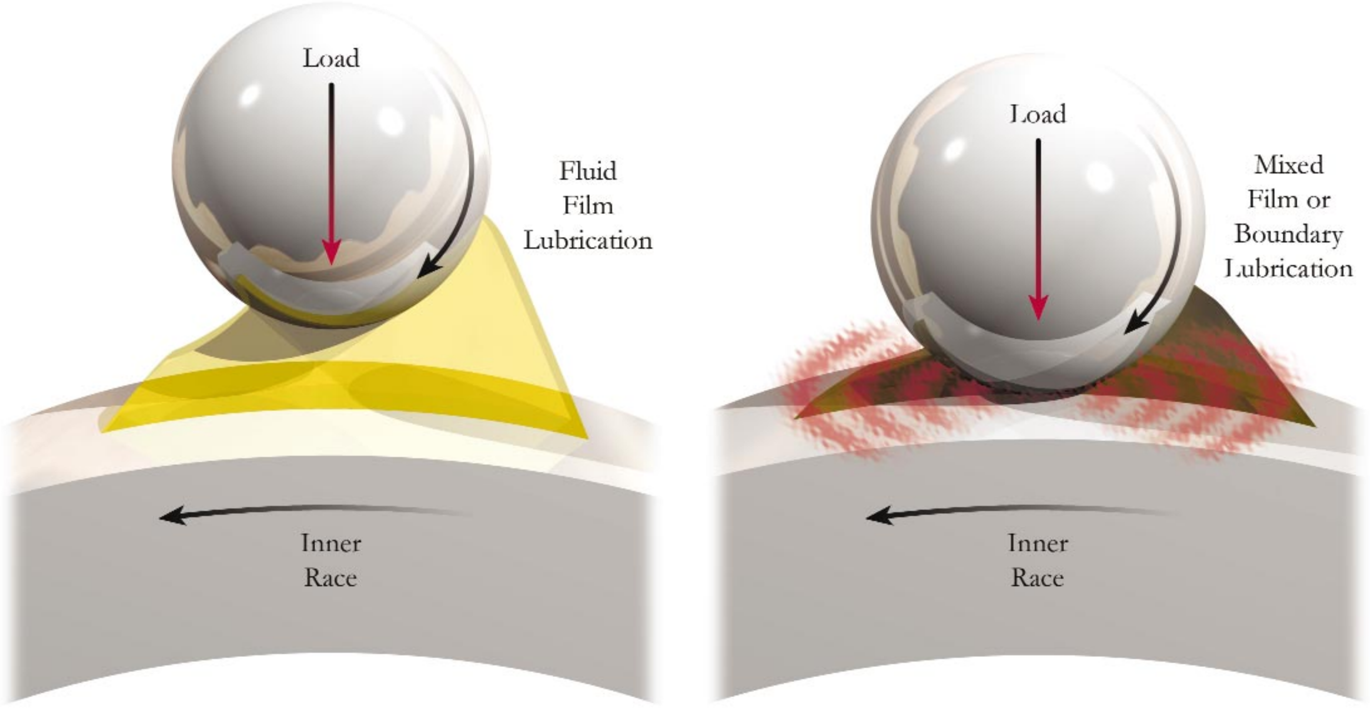


Figure 2. Normal Load Versus Inadequate Lubrication That Can Lead to Surface Degradation

viscosity, further analysis can determine the specific cause of the change. While there are more causes of increases in viscosity rather than decreases, both can result in the lubricant's failure to perform as expected. The following is a basic overview of root causes of viscosity change (see Trouble-shooting Viscosity Excursions article):

An increase in viscosity can indicate:

- Alignment/Balance/Overloading (thermal failure)
- Water contamination
- Air contamination/Foaming
- Wrong lubricant
- Overheating/Oxidation
- Coolant contamination
- Additive depletion (oxidation)
- Corrosion wear conditions (oxidation)
- Base stock failure (volatility, oxidation, thermal degradation, etc.)

A decrease in viscosity can indicate:

- Fuel/refrigerant dilution
- Wrong lubricant/mixing incompatible oils
- Cracking (very high temperatures)

Monitoring Viscosity Online

The Oil Security System automatically monitors the viscosity of oil lubrication and provides an easy-to-understand evaluation. Upon completion, if a caution or alert condition is reported, a yellow and red LED is activated. An LCD screen automatically provides additional information relative to the LED indication. The total time for analysis is less than two minutes and includes viscosity, water contamination detection and oil temperature data.

The standard Oil Security System is programmed for ISO VG 68 and ISO VG 100 fluids. Trico can program the OSS for specific viscosity and water contamination levels to specified customer requirements. Algorithms are utilized to compare online oil viscosity with the lubricant's specification (Figure 3). Both synthetic and mineral base oils can be monitored, with some potential deviation from the Viscosity Index of some oils. The Viscosity Index (VI) is a dimensionless unit that characterizes the change in viscosity with respect to the change in temperature. The higher the VI of an oil, the less tendency for its viscosity to change with change in temperature.

Although it is difficult to determine the safe range for all applications, a variance of up to plus/minus 15 percent can be generally considered suitable and still have good lubrication. However, even smaller changes in viscosity can be symptomatic of other, more harmful conditions, such as oxidation. Since the OSS is intended as a first indication device, percent accuracy within five percent should be considered acceptable. For example, if it is understood that the acidity of the oil has a tendency to increase during use, the viscosity change can be monitored as the first indication of an acid number increase (Figure 4).

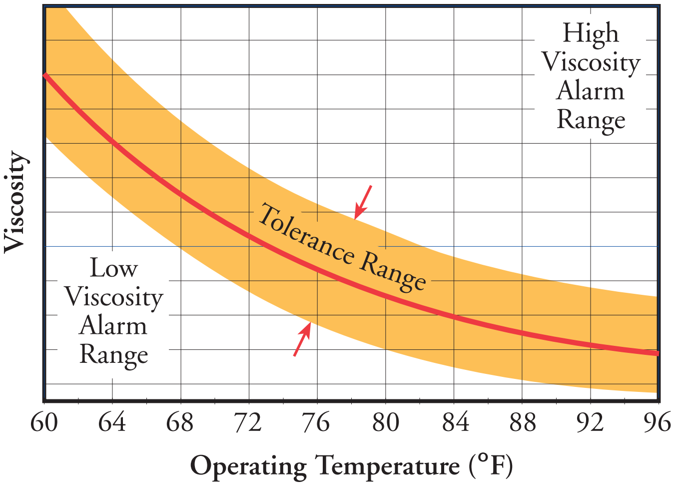


Figure 3. Comparing Online Viscosity with Lubricant's Specifications (Tolerance Range)

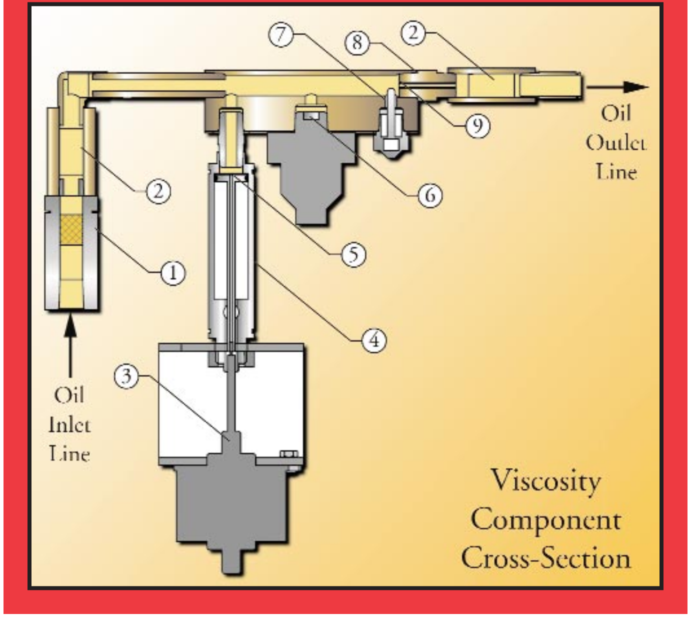
Monitoring Moisture Online

In addition to viscosity, the OSS continuously monitors dissolved water in oil in percent of the oil's ability to adsorb moisture, otherwise known as the relative humidity of the oil. The more common measurement of water contamination levels is in parts per million (ppm). One of the inherent flaws of ppm is the lack of relative temperature. The higher the temperature of the oil, the more water it can safely hold. The OSS measures the relative humidity, which many believe is a more useful measurement because the acceptable concentration in ppm can vary with temperature and from one oil to the next (Figure 5). For example, 500 ppm may be considered safe at 140°F (60°C) but may be damaging at 95°F (35°C). Additionally, 500 ppm at 140°F (60°C) in one type of oil may be damaging in another. The OSS measures and displays the percent relative humidity of the oil in percent, with 80 percent considered the highest safe level.

Basic Operation of the OSS

The OSS automatically measures the viscosity once every 24 hours, or as defined by a measurement request from the operator using the keyboard/display interface. The unit primes itself by cycling several times to ensure that a fresh sample of sump oil is checked - not residual oil in the inlet line. The oil is first filtered to eliminate particulates and air, increasing the accuracy of the test. The time and length of the plunger stroke are constant, making pressure differential across the capillary tube (restrictor) the variable. The ceramic restrictor is an accurate "tube" with a specific diameter-to-length ratio for viscosities in the ISO 32-100 range. The pressure and temperature measurements are converted to viscosity using a programmed algorithm based on the capillary efflux priciple and displayed in percent deviation. If this is less than +/- 15 percent the oil is considered serviceable.

1. Inlet Filter
2. Check Valve
3. Stepper Motor
4. Oil Cylinder
5. Plunger
6. Pressure Transducer
7. Temperature Thermocouple
8. Ceramic Restrictor Housing
9. Ceramic Restrictor



Easy-to-understand keyboard graphics combined with user-friendly indicators and LCD screen help make the OSS a reliable monitoring system for a variety of users. Online oil condition monitoring helps reduce maintenance costs by eliminating unnecessary oil changes and sampling. The Oil Security System can enhance current plant maintenance programs by providing the first indication of change.

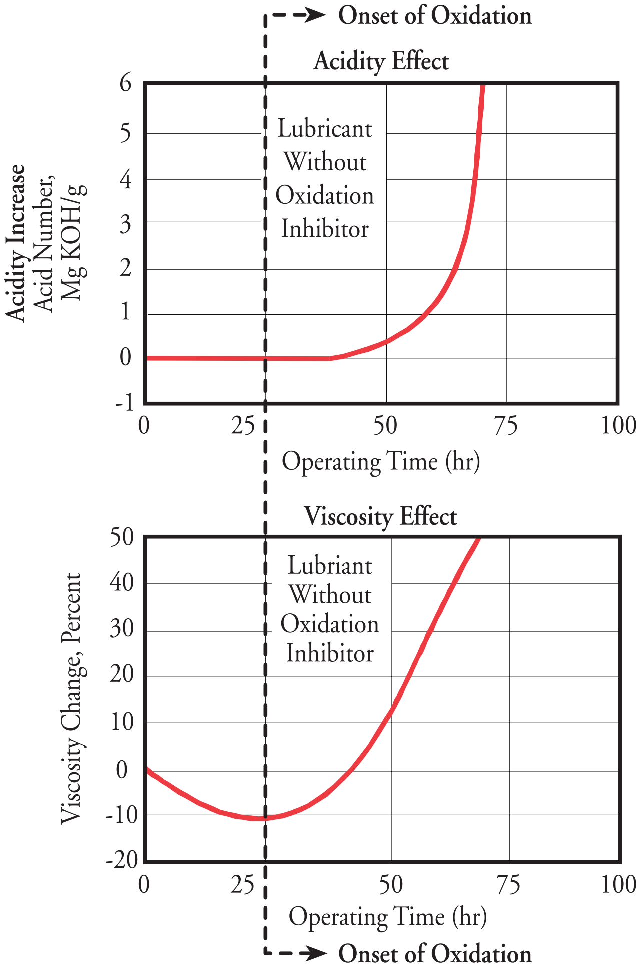
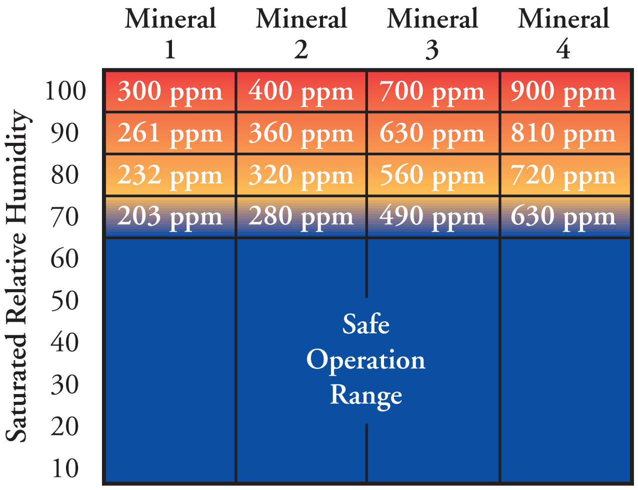


Figure 4. Viscosity Increases Acidity



Saturated Relative Humidity	Mineral 1	Mineral 2	Mineral 3	Mineral 4
100	300 ppm	400 ppm	700 ppm	900 ppm
90	261 ppm	360 ppm	630 ppm	810 ppm
80	232 ppm	320 ppm	560 ppm	720 ppm
70	203 ppm	280 ppm	490 ppm	630 ppm
60	Safe Operation Range			
50				
40				
30				
20				
10				

Figure 5. Measuring Relative Humidity

Trouble-Shooting Viscosity Excursions

By James C. Fitch

When an oil's viscosity makes a significant change it is meaningful. The majority of the characteristics associated with wrong, contaminated or degraded lubricants will cause a change in viscosity. Restated, when trending the viscosity of a used oil and no reportable change occurs, one can conclude that many of the things that could be happening to the oil are not yet occurring. These include oxidation, shear thinning, thermal degradation and many other common condemning conditions.

The signs of viscosity change are numerous. For many organizations, improperly diagnosed causes lead to problem reoccurrence (from the same cause) with each oil change. This occurs when oil labs see a change in viscosity and only recommend the oil compartment be drained and the lubricant replaced.

This article was written to provide an organized listing of common and not-so-common reasons for nonconforming lubricant viscosity. The varying applications of lubricants are so extensive and records of viscosity failures of in-service lubricants so incomplete, it is likely that many conditions responsible for viscosity extrusions have been overlooked here. The author would appreciate suggestions and comments from readers on any known causes of lubricant viscosity change not covered in this article.

How Viscosity Changes

Think of an oil's molecules as a large basket of mixed whole fruit. When you tip the basket, the fruit becomes a fluid body and flows out of the basket. In the basket there are cherries, plums, lemons, apples, grapefruit and melons. The fruit are different sizes and weights just like the molecules of common mineral oil. When crude oil is refined, the molecules are separated by their molecular weight into broad groups (small, medium and large for instance). An oil's viscosity basically correlates to the average size of the molecules of a given oil, i.e., small molecules are associated with low viscosity (thin oil) and large molecules with high viscosity (thick oil).

To change the viscosity, the average size of the molecules needs to change. Most mineral oils of a particular viscosity have molecules of an assortment of sizes. However, if the oil viscosity is high, the predominant size is large. The opposite is true for a low viscosity oil. Going back to the fruit analogy, the viscosity of the basket of assorted fruit would change if all the cherries were removed. This would increase the average size of the fruit and the viscosity. In the case of a lubricant, hot-running oil can boil off small molecules, creating the same effect.

To decrease the viscosity, the melons could be quartered to make them smaller. With oil, molecules can "cleave" or crack into pieces when they are exposed to extremely high temperatures. Another way to reduce the viscosity of the fruit basket would be to add more cherries, lemons and plums to the mix. This is similar to adding a low viscosity oil to a higher viscosity oil. The blended viscosity is somewhere in between the two. This type of thinning also occurs when a motor oil is contaminated with fuel.

The following summarizes how viscosity can change using our fruit basket analogy:

Decrease Viscosity:

1. Add more small fruit (mixing fuel with oil).
2. Remove some of the large fruit (electrostatic removal of oxide insolubles).
3. Cut the larger fruit into smaller pieces (shear thinning of VI improvers and lubricant cracking).

Increase Viscosity:

1. Add more large fruit (adding a more viscous make-up oil).
2. Remove some of the small fruit (boiling off light hydrocarbon fractions).
3. Glue several small fruit into a large poly-fruit cluster (oxidation, polymerization, etc.).

Zero-sum Viscosity Effects (two simultaneous offsetting events):

1. Small fruit and large fruit are added at the same time (when motor oil is contaminated with both fuel and soot, the fuel decreases the viscosity and the soot increases it.).
2. Cleave (cut into pieces) large fruit and remove small fruit at the same time (high temperatures thermally crack oil molecules to evolve gas that evaporates out of the oil).

Early Detection, Key to Health Management

In some cases, slight viscosity changes are normal; for instance, the minor shear thinning of VI improvers of an all-season hydraulic fluid. However, in other cases, an oil's change in viscosity might be the first indication of a more serious problem. For example, when an oil loses its oxidation stability the viscosity will trend upward. If the problem is not recognized and corrected, an innocuous five percent uptick in viscosity soon becomes a 50 percent uptick, rapidly increasing to 500 percent. In such cases, the worse things get, the faster they worsen. So early detection is the strategic imperative.

There are two important strategies one should apply. The first is to set a proper baseline (don't use published "product typicals"). Because the viscosity of a new oil can vary as much as 20 percent and stay within its designated ISO Viscosity Grade, the actual starting viscosity must be measured and recorded. After all, it would be rather difficult to pick up a 10 percent shift in the viscosity of an in-service used oil if the correct starting viscosity is unknown and assumed to be somewhere in the 20-percent range. It is better to measure the new lubricant's viscosity in the same way you are planning to monitor the used oil's viscosity, with the same instruments, same temperature, same procedure, etc. Because some lubricants are blends of fluids from different batches, sometimes progressively mixed new and used oils in a large reservoir, the "blended" starting viscosity is best set as the baseline, as opposed to the viscosity of any single batch of new oil.

Once a lubricant has been baselined, set limits. Many oil analysis software products will do this automatically. Because both southward and northward viscosity excursions are worthy of concern, limits in both directions must be set. This, in effect, puts a "band" or "envelope" around the oil's baseline viscosity. If the viscosity should trend higher or lower by significant measure, a limit is breached and the condition is flagged or alarmed.

Most top-shelf oil analysis programs apply tight limits above and below viscosity baselines. For crankcase oils, viscosity is typically measured at 100°C (212°F) while nearly all other lubricants are tracked at 40°C (104°F). If a reliable viscosity baseline is in place, it is recommended that cautionary and critical limits be set. Figure 1 suggests some limits conventionally used for both crankcase and industrial lubricants. Once the baseline and limits are in place, data from used oil analysis becomes easier to understand. Refer to the troubleshooting chart in Figure 2 as a guide on how to interpret nonconforming viscosity data.

Impact of Specific Gravity on Viscosity

Most commercial oil analysis laboratories deploy the use of kinematic viscosity using gravity flow capillary viscometers according to ASTM D445 (IP 71S1/97). One well-known limitation or interference relating to kinematic viscosity measurement occurs when an oil's specific gravity

Limit	Crankcase Oils**	Industrial Oils**	Severe Environment Industrial Oils**
Critial (upper)	+20%	+10%	+7%
Caution (upper)	+10%	+5%	+4%
Caution (lower)	-5%	-5%*	-5%*
Critial (lower)	-10%	-10%*	-10%*

* Twice this amount for oils with VI improvers.

** Crankcase oil limits based on cSt @ 100°C, industrial oils based on cSt @ 40°C.

Note: Severe environment oils are at high risk for thermal and oxidative degradation.

Figure 1. How to Set Viscosity Limits

What Causes Viscosity To Change

The following presents a number of common and some not-so-common causes of viscosity change in lubricants by causal group. Some of those listed below are only theoretical "possible causes" that have never been reported specifically or are difficult to confirm from the available data.

I indicates the cause typically INCREASES viscosity
D DECREASES viscosity
E EITHER causes to increase or decrease

Wrong, Mixed, Topped-Up or Doped Lubricants

- More viscous wrong or topped-up oil . . . . **I**
- Less viscous wrong or topped-up oil . . . . **D**
- Retrofit additive treatments . . . . **E**
- Bleed and feed treatments . . . . **E**
- VI improvement treatments . . . . **I**
- Incomplete drains. When an oil compartment is drained and charged with a new lubricant, as much as 20 percent of the former oil is often left to mix with the new oil. Hydraulic systems and circulating lube oil systems are often not drained completely, leaving fluid in lines and components. Depending on the viscosity difference between the two oils, this will cause a new hybrid "blended viscosity." . . . . . **E**
- New make-up oil added to sheared (VI Improver) in-service oil . . . . **I**
- Bulk transport lubricant mixes, cross-contamination . . . . **E**
- Polyglycol synthetic mixed with a mineral oil . . . . **I**
- Phosphate ester with mineral oil . . . . **I**

Contaminated Lubricants

- Diesel or gasoline fuel contamination (raw fuel) . . . . **D**
- Diesel fuel contamination (cooked fuel blow-by) . . . . **E**
- Bunker fuel mixed with motor oil . . . . **I**
- Water contamination . . . . **I**
- Grease contamination . . . . **E**
- Air contamination . . . . **I**
- Refrigerants . . . . **D**
- Nitric oxides (from combustion blow-by) . . . . **I**
- Soot Load . . . . **I**
- Glycol contamination (raw and cooked) . . . . **I**
- Natural gas dilution . . . . **D**
- Microbial contamination (live and dead) . . . . **I**
- Aggregates in the oil . . . . **I**
- Superabsorbent gels (from water removing filters) . . . . **I**

Lubricant Losses

- Loss of water from a water-based hydraulic fluid . . . . **I**
- Volatility from high temperature operation (loss of light ends) . . **I**
- Gas evolution (from Gamma radiation for instance) . . . . **E**
- Vacuum-distillation induced evaporative losses . . . . **I**
- Electrostatic removal of oxide insolubles and carbon fines . . . . **D**
- Filtering out solid additives and amorphous lubricant insolubles (additive floc, friction polymers, sludge, oxides, etc.) . . . . **D**

Degraded Lubricants

- Cracking/thermal degradation . . . . **E**
- Oxidation (oxi-polymerization) . . . . **I**
- Nitration (the oil) . . . . **I**
- VI improver sheardown . . . . **D**
- Hydrolysis (caused by water contamination) of synthetic esters . . . . . **D**
- Microdieseling due to entrained air bubbles . . . . **E**
- Generation of suspended friction polymers . . . . **I**
- Waxy suspensions and wax curd/sludge . . . . **I**
- VI change . . . . **E**
- Additive reactions with sodium hydroxide (caustic cleaner used in washdowns) . . . . **I**

Sampling Related

- Sampling sludge, sediment, coagulants, water, etc., from low points in the system or tank . . . . . **E**
- Regenerative isolated hydraulic circuits (there can be a different viscosity in the tank compared to isolated zones of the system) . . . . . . **E**
- Sampling from gauge-line extensions instead of circulating live zones . . . **E**
- Sampling motor oil after extensive idling (fuel dilution) . . . . . . **D**
- Mislabeled sample bottle (wrong oil ID) . . . . **E**

Analytical or Instrument Causes

- Viscometer instrument errors . . . . **E**
- Reference standard errors (used to check calibration) . . . . **E**
- Temperature bath problems/inconsistencies . . . . **E**
- Water in oil, with the 100°C viscosity test (water boils during the test) . **E**
- Viscometer comparators where the oil's VI differs from the instrument reference VI . . . . **E**
- Specific gravity estimation errors (converting absolute viscosity to kinematic, associated with some instruments) . . . . . . **E**

changes. Typically it increases as the oil ages or becomes contaminated. This can occur at the same time viscosity changes or it can occur independent of viscosity.

If specific gravity increases without a change in absolute viscosity (the oil's resistance to flow or shear) there will be a decrease in kinematic viscosity proportional to the change in specific gravity. While not a true viscosity change, it has the potential to be misrepresented as such. Examples of how specific gravity can increase viscosity include contamination (heavy solid and liquids), oxidation, evaporative losses, wear debris, glycol contamination, etc.

In many cases, when an oil's specific gravity increases there is also an increase in absolute viscosity. The resulting effect is an understatement of the reported increase in kinematic viscosity.

Getting the Most from Viscosity Monitoring

Adding routine viscosity analysis to a lubricant condition-monitoring program makes good strategic sense. From the many different conditions that influence lubricant viscosity, as listed on the previous page, a lack of viscosity change is comforting indeed. For this reason, many reliability programs add viscosity analysis onsite and check critical lubricants and hydraulic fluids regularly.

When nonconforming viscosity trends occur, best practice is to determine the root cause of the excursion so that it can be prevented from reoccurring. This is particularly true in cases where viscosity changes early in a lubricant's life and/or when large shifts in viscosity are observed.

Finally, as with most oil analysis instruments and maintenance technologies, viscosity analysis alone does not provide a complete picture of everything that is happening to the oil and to the machine. Other tools and methods are equally important in deploying your condition-monitoring arsenal.

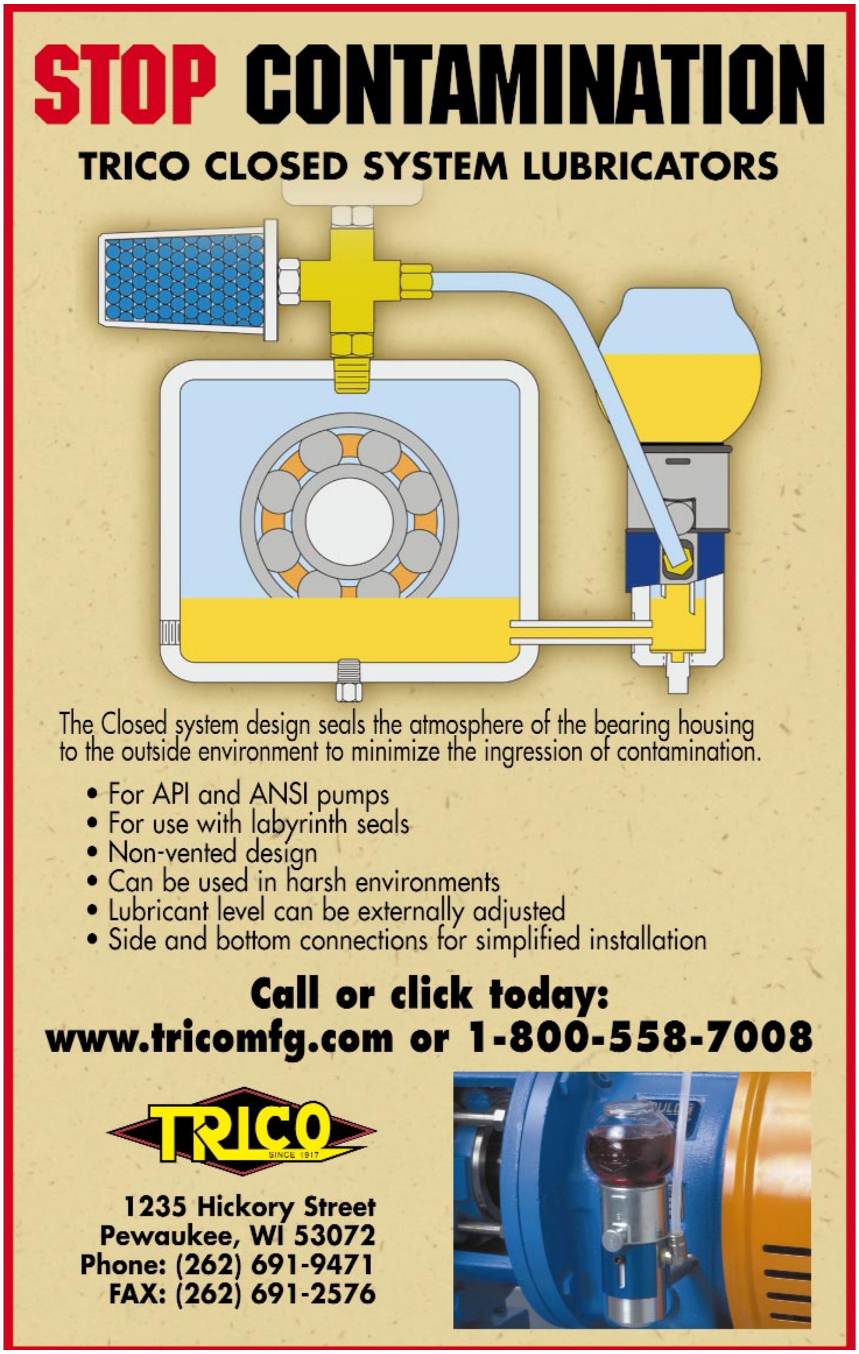


Figure 2. How to Use Viscosity Analysis