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WHY THE OIL IN YOUR AIR COMPRESSOR MATTERS

ALSO:

The Anatomy of a Filter Inspection Report
Demystifying Oil Analysis

NORIA

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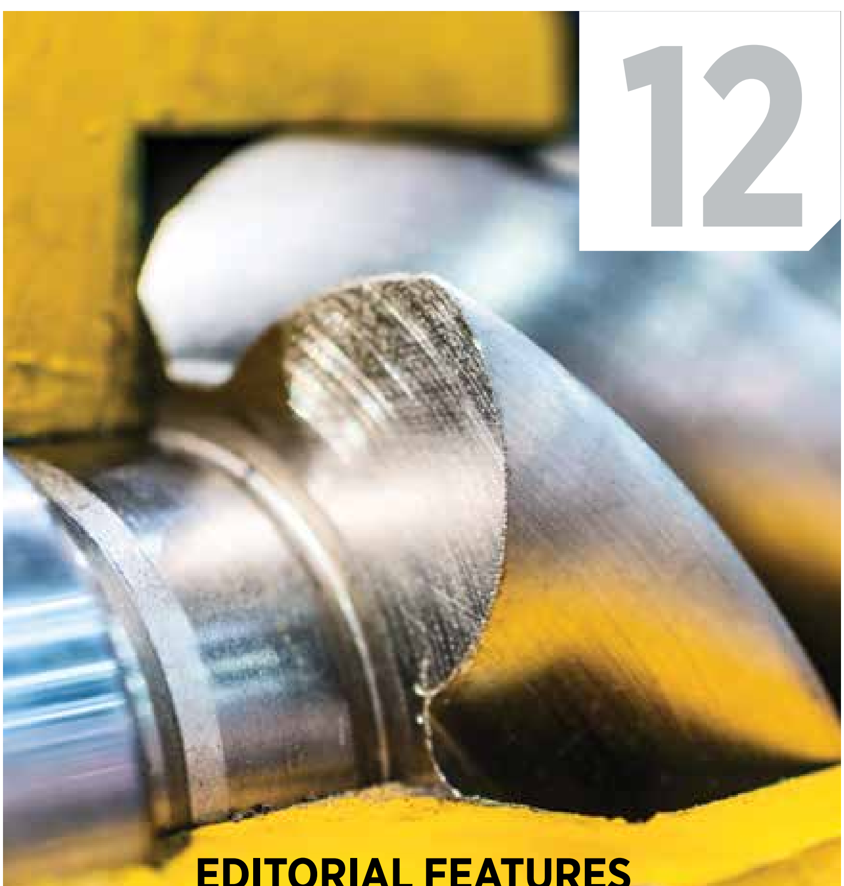
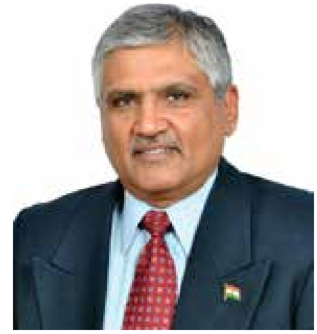
AS I SEE IT

COVER STORY



EDITORIAL FEATURES

Publisher's Note



Lubricants selected for compressor applications generally depend upon eight conditions; the type of compressor, the type of gas being processed, discharge pressures and temperatures, lubricant oxidation, rust and foaming resistance, hydrolytic stability, carbon deposit forming tendencies (particularly at discharge valves) and compatibility (with seal materials and the gas itself).

Even though today's top quality mineral base oils are frequently used as compressor lubricants, the trend is toward synthetic fluids, most notably; polyglycols, diesters, polyol esters, phosphate esters (for compressors requiring fire resistant lubricants) and polyalphaolefins hydrocarbons. The primary reasons for their use are their extremely high viscosity indices and superb oxidation resistance. A synthetic lubricant with a high viscosity index can reduce power consumption by up to 12%.

Moisture is a factor, particularly in air compressors, when they are allowed to run unloaded. This is because condensation occurs during unloaded periods when the cylinders cool below the dew point of the air remaining in them. This condensate can cause severe corrosion and rust deposits if not controlled. The lubricant must provide excellent hydrolytic stability. When using mineral based or synthetic hydrocarbon oils, water content should not exceed .5% (5,000 ppm). If polyglycol fluid is used, this lubricant can tolerate about .8% (8,000 ppm) of free water.

In self driven integral engine compressors, both engine and compressor pistons are connected to the same crankshaft. The running gear may also share a common crankcase. As a result, diesel engine oils are frequently used and may be mineral base or synthetic of similar viscosity grades as noted previously. Cylinders used in single and two stage crosshead or trunk type compressors processing air or inert gases, are usually lubricated using the same oil found in the crankcase.

Another factor that determines cylinder oil selection is the operating temperature. Thin films of compressor cylinder oil will inevitably reach the discharge valves. The hot metal surfaces create severe oxidizing conditions and the formation of carbon deposits. These deposits restrict the discharge passages, further increasing discharge temperatures contributing to more deposits. Eventually a hot spot will develop which may result in a fire or explosion. Lubricant selection and condition monitoring are critical considerations in reciprocating compressor operation and not enough attention is paid to these requirements for safety and insurance reasons.

Conversion To Synthetics There are two very important considerations when converting any compressor system to synthetic lubricants. The first is that some synthetics will dissolve mineral base oil deposits and a viscous tar-like substance may develop, plugging piping, valves, intercoolers, and heat exchangers. Conversion to synthetics therefore may require a complete flushing and cleaning of the entire system before installing the new fluid. Diester fluids in particular have excellent solvency and are frequently used as flushing fluids. Secondly, all synthetic fluids may not be compatible with all seals or sealing materials. It is also necessary to determine if the synthetic fluid being considered is compatible with machine coatings or paints often found on the inside surfaces of reservoirs or other components. In general, polyglycols, diesters, polyalphaolefins and alkylated aromatics are compatible with the following seal materials

In addition to the cover story on Oil & air compressor oils, we have several other articles on lubricant monitoring, reception & storage and handling application. It also includes articles on lubricant contamination control & reconditioning, analysis & troubleshooting and lube-tips and others.

We are eager and happy to receive your feedback on ways we can make our magazine more informative and interactive for our readers.

Wish you a very happy Dussehra & Diwali.

Warm regards,

Udey Dhir

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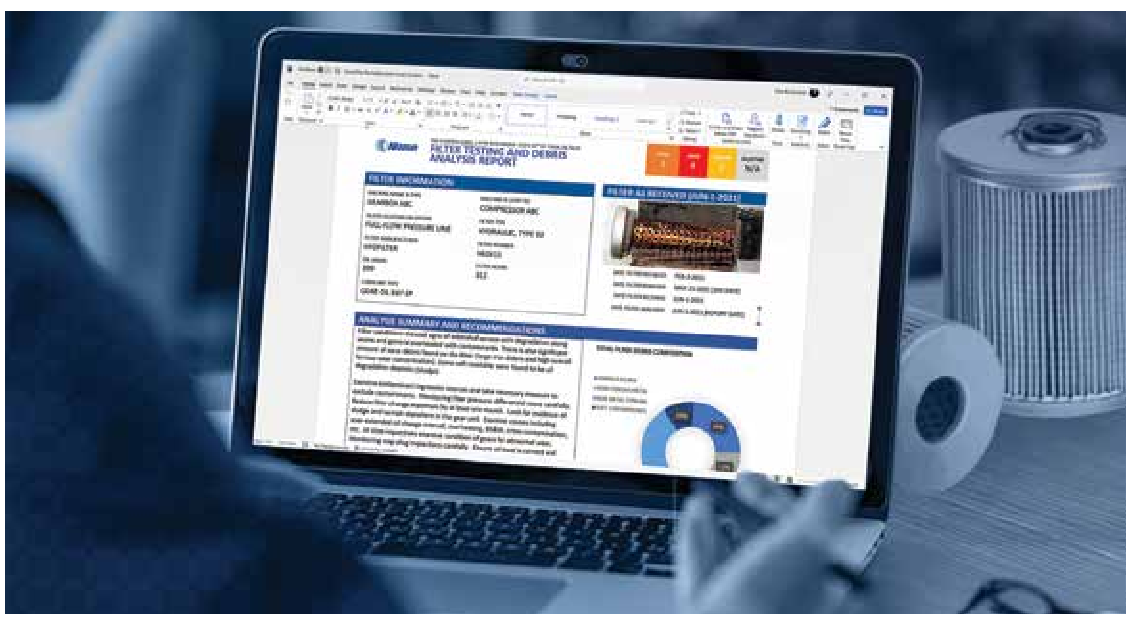
The Anatomy of a Filter Inspection Report

"People engaged in condition monitoring are oblivious to the wealth of information found in used filters."



When the history of the condition monitoring field is written, there will likely be a chapter, or at least a few pages, on the odd paradox surrounding how infrequently use of used filter testing was employed (in the beginning). The assumption is that filter testing will eventually enjoy widespread use as misconceptions and ignorance of its benefits fade away. As I write today, the vast majority of people engaged in condition monitoring are oblivious to the wealth of information found in used filters.

The target application relates primarily to critical equipment, i.e., those that are expensive to repair or have high downtime costs. A well-engineered condition monitoring program should align the data being gathered with the failure modes we seek to detect. Granted, these are failure modes of highest risk to the machine, based probably on occurrence and consequences (business interruption, etc.).

Think of the logic behind this. Filters are intended to purify by removing solid contaminants that are harmful to the oil and the machine. If the filter is doing a good job, it is removing contaminants as fast as they are entering (ingression). This is known as mass balance. The

Figure 1: This filter is loaded with sludge from a system with severe electrostatic discharge issues.

number of particles coming into the oil system (particle ingression) equals the number being caught by the filter (particle removal); this achieves a stabilized and controlled oil cleanliness level. While particle removal is advantageous to the oil and the machine, it gets very low marks when the oil being cleaned is sampled for analysis.

The reasons for doing oil analysis fall into three categories: fluid properties analysis, fluid contamination analysis and fluid wear debris analysis. Filtration can have a marked, negative impact on contamination and wear debris analysis, two of the three categories.

Wouldn't you agree that it is valuable to know about dirt and other abrasive contaminants? It is the leading cause of failure for many machine components, especially bearings. One could argue it's even more important to know the amount and characterization of wear debris generated by your machine.

We need to stop lying to ourselves. In many cases, the oil is not the best place to get answers to those questions. The answers (particles) were briefly in the oil for sure, but they were quickly removed and now reside in the interstices of the filter.

Over time, your filter becomes loaded with data, like a hard drive. But sadly, the filter is usually discarded, along with the data it's carrying. In contrast, a filter that's skillfully inspected and analyzed tells a story about

Figure 2: Pleat pack should demonstrate how particles are distributed

the history of the machine and the oil. Yes, it is often more expensive than oil analysis by itself. However, you can't analyze what isn't there. Go to where the data resides, not to where it used to be. Don't be a penny wise and a pound foolish.

Many of the major labs that provide oil analysis services also provide used filter analysis. Noria offers used filter testing as well. The report shown in figure 5 is an example of data that can be extracted from a filter as received by the lab for inspection and analysis.

Visual Inspection of the Filter

Make sure you're using a lab familiar with how to examine a used filter. There are many subtleties requiring special knowledge and skills. These relate to the filter media, the center tube (core), the seals, varnish (end caps and center tube),

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and adhesives. The complete filter needs to be examined, with findings included in the comments section of the report.

Next, the filter should be dissected. The media pack will need to be cut away (or sheared) to allow the pleats to be spread open like an accordion. The condition of the pleat pack should be closely examined for structural and manufacturing integrity. Look for holes, breaks and sludge.

The individual plies of the pleat pack can then be peeled away to allow the actual filter media to be examined (usually the center ply). Some filters have as many as six different plies. Many labs use light tables to look across the filter media for inconsistencies.

A system should be used to characterize or grade the visual observations of the filter and media. For the filter in the through "significant concerns" were noted. A description of the nature of these concerns is provided in the table. The better labs will include annotated photos of the filter and media in the report.

Wear Debris and Contamination

Removing contamination is the primary function of the filter. Look for evidence that the filter is doing this job and the integrity of the media has not been compromised (cracks, ruptures, etc.).

Particles can easily be removed from the filter media for both soft and hard analysis. One method is the particle resuspension method using an ultrasonic bath. Other labs backflush the filter or swatch of media to extract the particles for examination. Either method is suitable.

The particles can then be examined visually, similar to analytical ferrography. This can best be done by preparing a micropatch or ferrogram (or both). Contaminant and wear debris characterization can follow the methodology described in ASTM D7684.

Figure 3: Preparation of a micropatch

Photomicrographs of salient (meaningful) particles should always be included in the report. Ideally, these images are annotated or have a caption with descriptive information. Scanning electron microscopy (SEM) images are often provided by labs as well.

Elemental analysis is important to better understand the composition of the particles. Examples of elemental data of particles extracted from a filter are seen on page two of the example report (Figure 5). The relative concentrations of metals help provide context about the type of particles and their origin. The data can be compared to previous filters to alert to changing conditions.

Different methods can be used to analyze particles elementally. These include Inductively Coupled Plasma (ICP), by acid digestion and x-ray fluorescence spectroscopy (XRF). SEM-ESD is another option.

Varnish & Sludge

Many filters will be loaded with soft contaminants. Various methods can be used to better understand the origin/formation mechanism of varnish insolubles, including FTIR and solvent extraction. Colorimetry is also very useful. If soft contaminants are found, their characterization should be included in the report as well.

The number of companies adding used filter analysis to their condition monitoring programs has greatly increased over the past ten years. Particles have a story to tell. But to get the full story, go to where the particles are, not just to where they used to be. *ML*

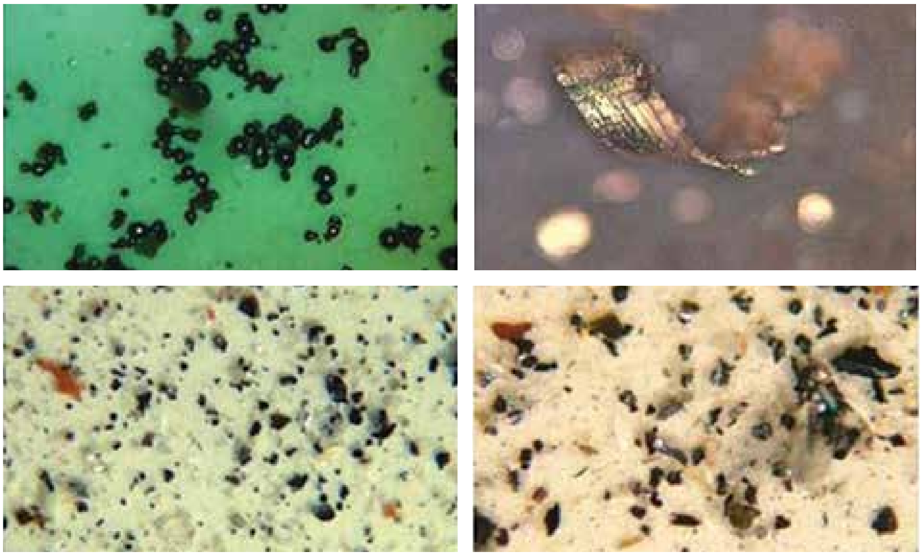

Figure 4: Micropatch debris field using the resuspension method to remove particles from the filter for inspection and analysis.

About the Author

Jim Fitch has a wealth of "in the renches" experience in lubrication, oil analysis, tribology and machinery failure investigations. Over the past two decades, he has presented hundreds of courses on these subjects. Jim has also published more than 200 technical articles, papers and publications. He serves as a U.S. delegate to the ISO tribology and oil analysis working group. Since 2002, he has been the director and a board member of the International Council for Machinery Lubrication. He is the CEO and a co-founder of Noria Corporation. Contact Jim at jfitch@noria.com.

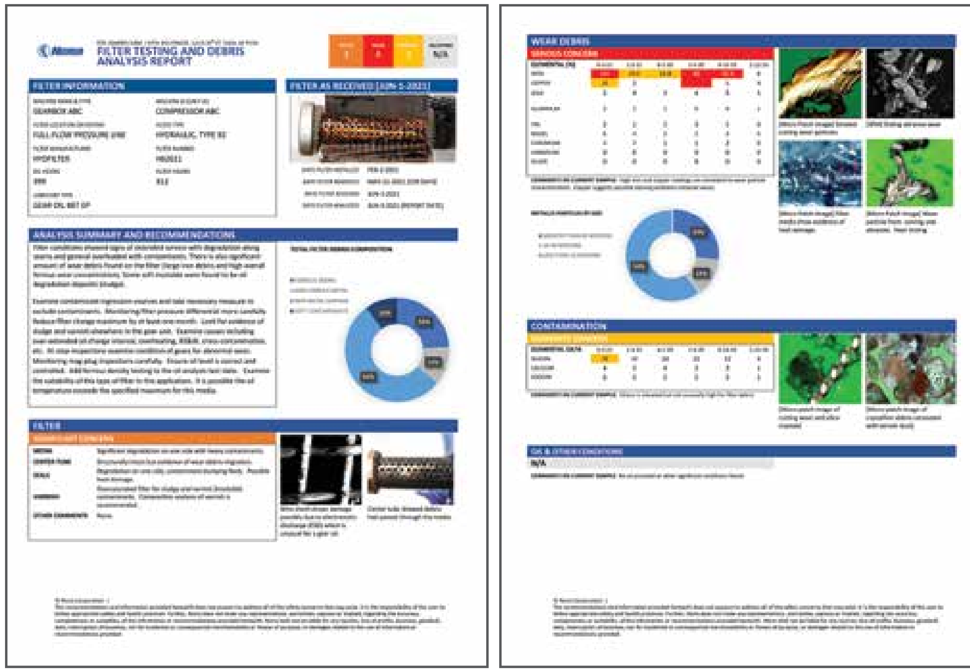

Figure 5: An example of Noria's used filter analysis report.

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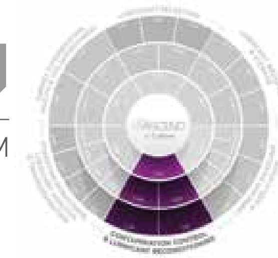

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Level:
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Stage:
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About:
Proper contamination control training allows operators to identify contamination sources and establish preventative and corrective measures.

"Wow, there is so much I didn't know about lubrication!" This is the typical response after someone attends a Machinery Lubrication course: a several-day learning journey through all sorts of topics. This includes learning about the functions of a lubricant, how to select the right lubricant for each application, how to manage them in storage and properly apply them to machines, and of course, all about monitoring lubricant and machine conditions through inspections and oil analysis.

But there are two specific areas of lubrication that must be communicated to nearly everyone working with and around plant equipment: Contamination Control and Inspections. In this article, I will review a few of the benefits of contamination control training as it drives culture change and long-term sustainable growth with plant reliability.

What is Contamination Control?

Consider first that contamination is defined as "any foreign or unwanted substance that can have a negative effect on system operation, life or reliability." This is much more than just solid particulates from the environment; rather, it includes water, air, glycol, soot, fuel, etc. Even the wrong lubricant mixed into the current lubricant is a form of contamination referred to as cross-contamination.

Contamination control in the context of lubrication includes the "planning, organizing, managing, and implementing all activities required to determine, achieve and maintain a specified contamination level." Notice that neither the word "eliminate" nor "remove" is used in this definition; more on that later.

Don't Leave it to Instinct

A lot of what is important with contamination control is not intuitive, meaning that, until someone has training, they simply don't know what they don't know. Take, for example, the physical size of solid contaminants that could damage a rolling or sliding contacting component. Oil films are usually 5-20 microns for sliding contact (turbine bearings, gears, pistons, etc.), all the way down to less than one micron for rolling contact (rolling element bearing, gears, cams, etc.). Typical airborne particulates that ingress into machines are usually much smaller than 40 microns, which is the visibility limit of the unaided eye. This makes it common for there to be a misperception of the degree of cleanliness needed in and around lubricated machines. It is not intuitive for us to understand the importance of these virtually invisible contaminants with everyday practices. This is just one example of what must be learned through careful training — providing a discussion and explanation on why contamination control is important, rather than just telling them what to do and what not to do.

Creating a Balance Between Exclusion and Removal

It is often assumed that contamination control is just about filtration; this is far from the truth. While it is a big part of contamination control, filtration is only necessary because contamination is allowed to get into the oil (and the machine) in the first place. The actions that must be taken to control contamination include both exclusion (seals, breathers, clean new oil, etc.) and removal (mostly filtration). In fact, it will always be much cheaper (at least one-tenth the cost) to exclude a gram of dirt from getting into a machine than it is to remove it through filtration.

Nevertheless, neither exclusion nor removal is perfect — they must be considered together as a contamination control solution for critical machines. It must be learned through training that contamination control requires a balance of this two-part approach, just like our bodily caloric control, where we strive to burn more calories than we consume. For machines, we can monitor contamination levels, such as with oil analysis, to verify that this is staying in balance. If more contaminants are accumulating in the oil than are being removed, a contamination-induced failure can develop. It is important that those who make decisions about breathers, seals, filtration and other everyday oil sump management have learned about contamination control to ensure enough is being done to keep this in balance.

Realizing the Benefits

For decades, countless industry studies by OEMs and end-user groups have identified that contamination is the number one cause of wear on rolling element bearings, gears and the majority of lubricated components. Additionally, it is well established that the cost of controlling contamination through optimized best practices will be considerably less than the cost savings from mechanical wear-related failures decreasing over that period.

Then why is this not often realized? This is where training is needed. As mechanical wear occurs from moderate levels of contamination, it propagates a gradual Failure Development Period that appears largely uneventful to the untrained person. As the wear gets worse, eventually predictive maintenance (PdM) may trigger a corrective action through vibration analysis, inspections or other means. If this becomes a common occurrence, then a preventative maintenance (PM) task may get scheduled to replace these components on a fixed interval that is significantly less than the intended design life. And unfortunately, this is very common.

These PdM catches and scheduled PMs are rewarded, but these habits actually form a maintenance culture focused on reacting to failure rather than establishing proactive measures to recognize the root cause (contamination) and improve proactive maintenance (contamination control).

If a root cause analysis were done, it would be difficult to pinpoint one single cause. Rather, the root cause is usually a collection of bad decisions and practices that impact contamination levels. Good practices include everyday activities or decisions such as:

- Managing new oils by keeping them clean and dry before use.
- Transferring new oils in clean, sealable-and-refillable containers, filter carts or something similar.
- Managing machines' headspaces by using quality desiccant breathers or something similar.
- Monitoring contamination levels with particle counting on critical machines.
- Establishing filtration needs effectively, either through continuous stationary filtration or through periodic filtration with a filter cart.
- And many more daily activities like careful machine washdowns, keeping machine areas tidy and clean, walk-by inspections, etc.

The actions and decisions that influence contamination control are part of a collective effort involving nearly everyone working around the machines, including maintenance, operators, lube techs, reliability engineers, supervisors, etc. Similarly, when these teams go through contamination control trainings together, everyone builds a collective awareness and a better understanding of what each of their roles entails. The benefit of contamination control training multiplies as the importance is bought-in together, especially when the training takes place in-person as one group.

Ultimately, contamination control is everyone's responsibility. When training is provided for those responsible, it sets the tone from the top down that lubrication is not a trivial part of maintenance but instead requires carefully made decisions, quality daily actions, and, most importantly, it impacts the bottom line. It all requires a highly trained professional. ***ML***

About the Author

Bennett Fitch is the Chief Strategy Officer for Noria Corporation. He is a mechanical engineer who holds a Machinery Lubrication Engineer (MLE) certification, a Machine Lubricant Analyst (MLA) Level III certification and a Machine Lubrication Technician (MLT) Level II certification through the International Council for Machinery Lubrication (ICML). Contact Bennett at bfitch@noria.com.

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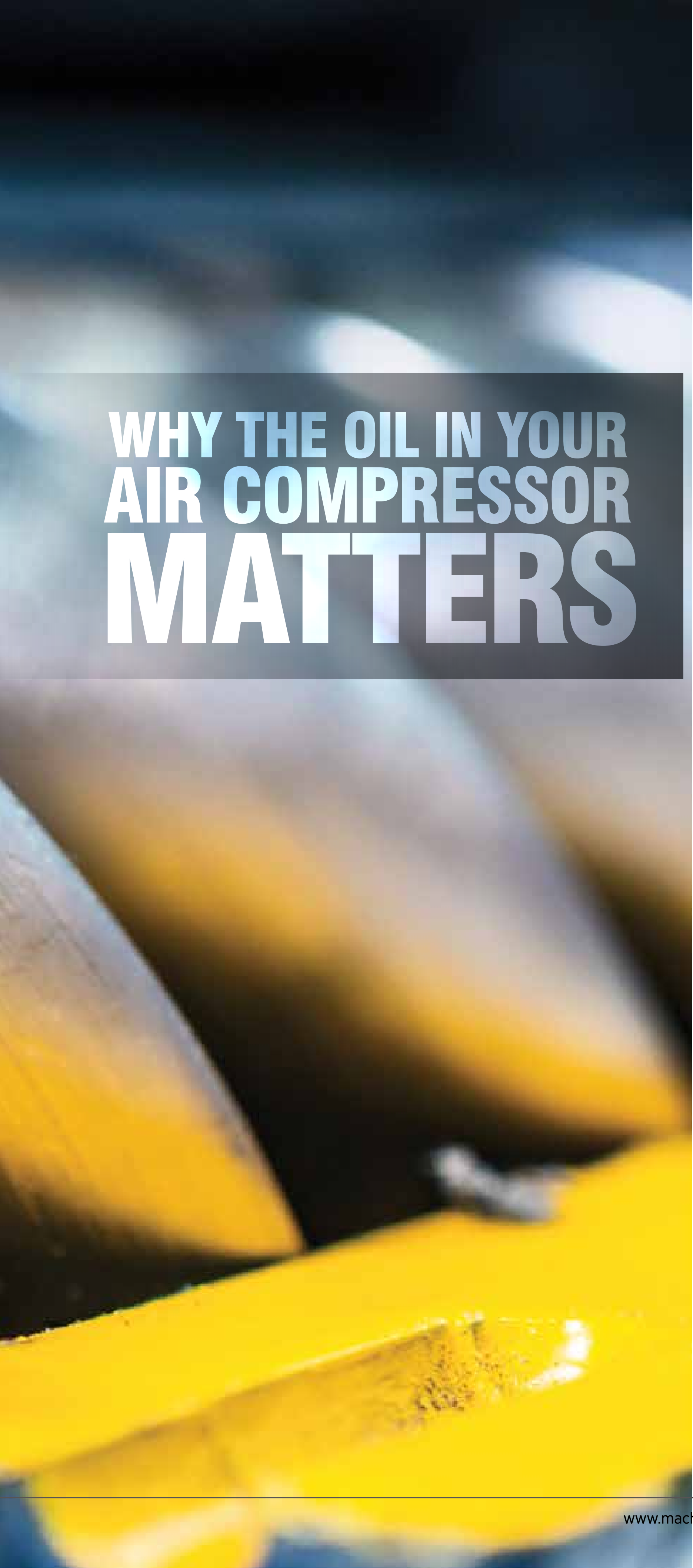


WHY THE OIL IN YOUR AIR COMPRESSOR MATTERS

Air compressors are the main component of compressed air systems, which are an essential part of any modern industrial plant. After air is compressed, it becomes a safe and abundant source of energy. Because of this, compressed air has been a necessary part of industrial processes for decades.

The most common air compressor design used across industries today is the screw compressor. This is because they are efficient, widely available, and come in a variety of sizes from 10 HP all the way up to 500 HP. Standard two-stage designs can also operate at up to 13 bars (188 psi) of pressure.

Troubleshooting challenges is an essential skill for any team tasked with keeping machinery running. Our team has spent years helping plants improve their processes and conquer challenges. During that time, we have refined our reliability and data analysis techniques. Since today's reliability programs often rely heavily on data and analytics, I will be sharing some figures about the amount of downtime associated with one of the smallest footprints inside a plant: the humble air compressor.

In general, the compressed air station will usually be around remove the 1.2-5% of the total cost of a plant's rotating assets. However, it can be up to 20% for general utilities and it can be up to 80% for industries like spinning and weaving, where it is necessary for the majority of production activity.

While the extent to which individual industries rely on compressed air will vary, most industries require compressed air for some part of their process and all will suffer from various levels of downtime if compressed air becomes unavailable or has its

Twin screw compressor

quality compromised. For example, 46-86% of downtime in industries like Fast Moving Consumer Goods (FMCG), assembly-based process, spinning and weaving, and steel plants can be attributed to compressed air. This downtime is a direct production loss everyone would like to avoid. This can usually be done by employing redundancy, but that strategy can only go so far.

Compressed Air Maintenance Strategy

The first thing on the mind of any management team considering compressor improvements should be mitigating the risk of downtime associated with compressed air. As I mentioned, redundancy is often the first strategy employed here, and this often makes sense – to a point. But buying backup compressors is not the only solution to the problem, nor does it always make financial sense to do so. On top of that, many OEMs and utilities teams spend unnecessary capital employing Preventive Maintenance on these assets, rather than using a more focused strategy.

The utility manager of a plant once asked me what he would save by discovering potential compressor failure earlier. He was currently buying a new compressor every year even though no production capacity was being added and no old compressors salvaged.

In order to answer his question, we need to go back to the basics of proper compressor maintenance and failure risk mitigation. Let's look at a case study to better understand these principles.

Case Study

In a modern, up-to-date steel plant the compressed air station was designed for 25% redundancy in order to ensure the maintainability of the plant, which is the time needed to get the assets back into production. Production could easily continue with three out of four compressors, giving the needed flexibility to the maintenance and supporting OEM teams to perform the scheduled preventive maintenance activities without impacting production. All seemed good and risk was mitigated.

For now, we'll disregard the high cost of spare parts and the three holding capacities – we'll discuss those later. The primary flaw of this type of maintenance plan is that it was purely time-based and didn't consider the possibility of "random" failures. Random failures are not usually that random; they happen mainly due to human error. We refer to them as random because their occurrence on a failure pattern curve is random. They are the flat part of the curve which illustrates the actual useful life of the asset (in our case, the compressor).

Luckily the plant was doing condition monitoring (CM) with the OEM to measure vibration and thermography, along with oil analysis when it was needed.

Their CM techniques and strategy were built on the P-F Curve and the ability of the measurements that were gathered to help them intercept failures early or at their inception. The most understood and widespread CM technique used in P-F Curve analysis

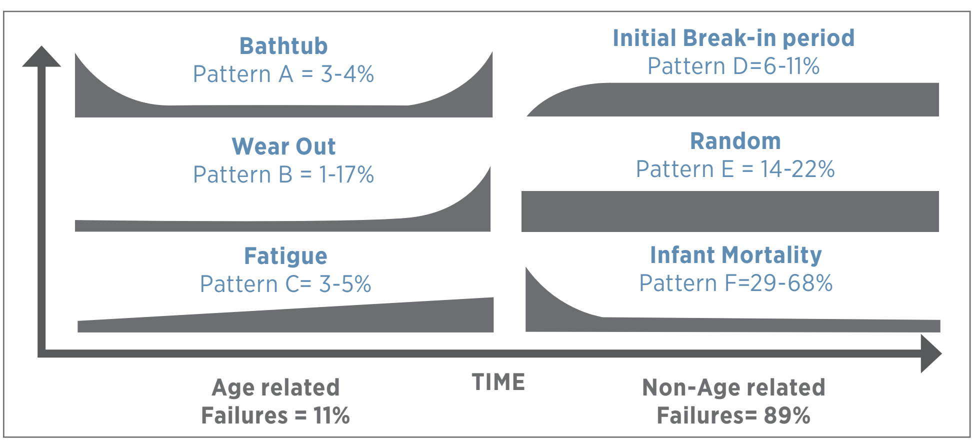


Figure 1: Equipment Failure Pattern Distribution

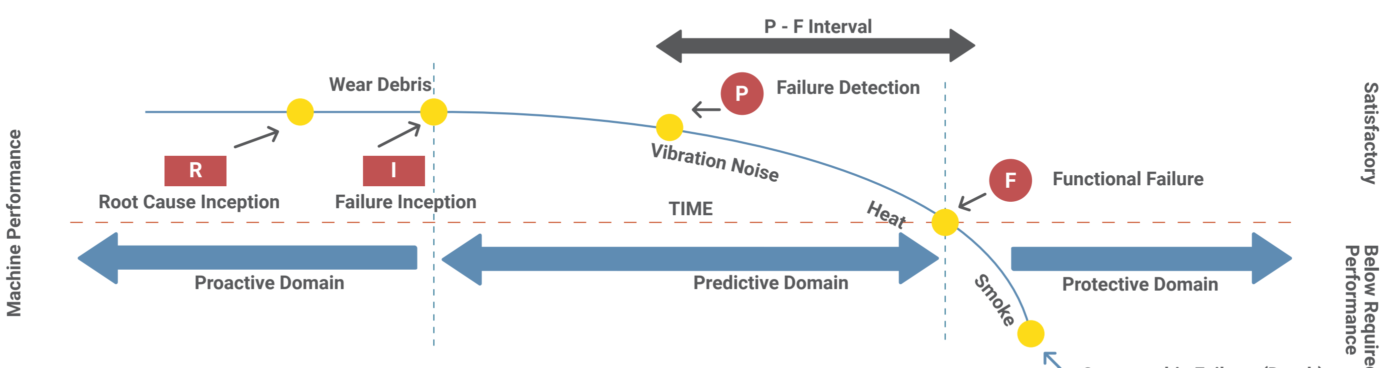


Figure 2: Diagram of the P-F Interval

is vibration, while the oldest is oil analysis.

The most challenging part of using a P-F Curve is actually getting the curve of the failure mode correct, based on accurate time frames between every stage of the failure (x axis is time).

The most important consideration here is determining how failures actually happen. It's been well documented that random failures account for the majority of what we see in the industry. It's also regrettably common for people to underestimate how fast the faults can develop given the particular circumstances.

In the case of our steel plant, we will observe an accelerated failure that consumed 68% of the life of the bearings in the air end of a compressor before anyone detected the potential failure. Failing to detect this problem resulted in the bearing enduring the equivalent of 16000 hours of operation in just 18 days (432 hours).

Screw Compressor Construction

In order to perform reliability analysis for any assets you have to understand the operational context of the machine, how it works, what components have the highest risk of failure, and what failure mode would impact the machine's reliability the most.

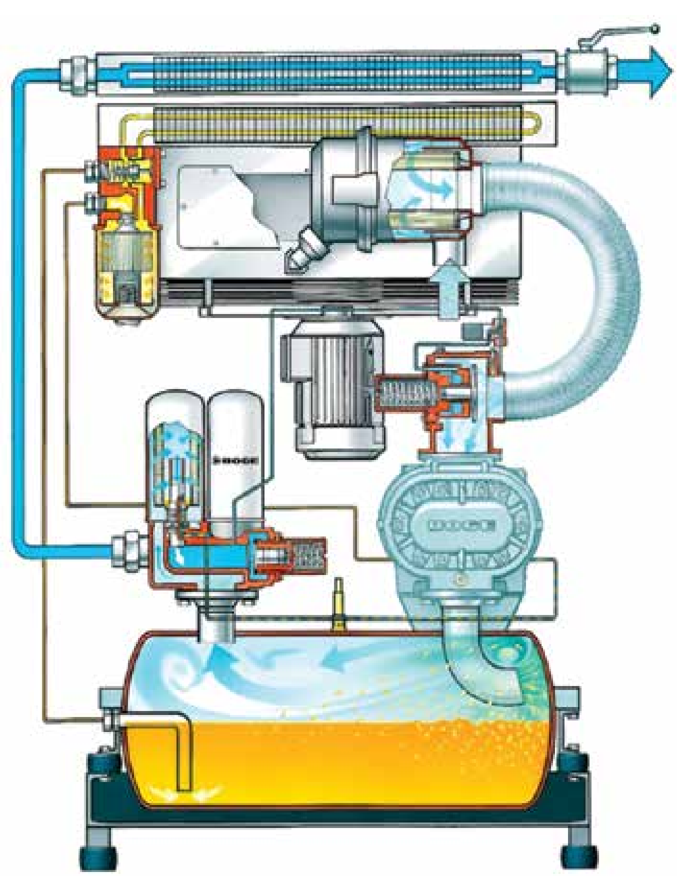


Figure 3. Typical air compressor configuration.

The machine in Figure 3 is an oil-flooded screw compressor, also known as an oil-injected screw compressor. It has an air end driven by an electric motor and uses the pressure generated by the air end to drive the oil in the lubrication circuit through the lubricated components as well as the filtration and cooling systems.

As you can see, the air enters the system through an air filter where the majority of destructive particle contamination should be captured. The oil and air are mixed upon entry on the top of the bearings and the air end begins compressing this mixture. After passing through the air end the temperature increases significantly, averaging between 73°-83°C, which is considered normal for this type of machine. The oil then drops into the settling tank by gravity and the compressed air leaves through the oil air separator, at which point it is cooled in the after cooler and leaves the compressor for further treatment. The oil takes a different path out through the filter and then the thermostatic valve on its way back to the air end.

How To Kill Your Bearings Quickly

The oil in our machines is a very critical asset. We must ensure that not only will it perform, it will also protect the bearings from excessive or sudden wear.

If you look closely at Figure 3, you will notice a hose providing the entry of ambient air after the filter. This is a weak point for this compressor that could initiate many failures if the maintenance team doesn't understand its failures modes or what to look for when they inspect the machines.

In our case study, a small crack in the plastic hose occurred after the air filter due to the wear and tear of the process. If you suspected that this crack was premature, you would be right. An incorrect control setup had been put in place which manipulated pressures in the hose. This was done in order to accommodate requests from operations to avoid low pressures in the production line. The frequency with which the machine cycled between loading and idling was too rapid. This cycling is something that is counted by any modern compressor controller since it is one of the primary root causes of many compressor failures. Once this hose cracked, it presented a golden opportunity for abundant and destructive contaminant like silica dust to enter the system.

Damage like this is an open invitation for dust particles of all sizes to enter at the worst possible location, bypassing the filter and landing directly on the defenseless bearings. What happened after that was predictable: the next vibration analysis indicated the bearings were failing.

An Upset Utility Team

Denial is a typical human behavior when we get news that we don't like. We try to find an alternative reality that disregards the inconvenient truths we've been confronted with. In this case, when the utility team was given the bad news about their bearings, their first reaction was to question the accuracy and integrity of the vibration measurements.

At the same time, I was asked to assist with the case to try to determine what happened. I wondered how a bearing could speed through the P-F curve 37 times faster than what was expected. Once I took an oil sample and analyzed it, the answer became clear. Since I have been using the **shock pulse** method for a long time, I quickly noticed that there was a possible contamination signature present in the system. The oil analysis confirmed my suspicions and told me just how much contamination there was: 37 ppm of silicon (elemental spectrometry) along with a 21/19/16 contamination code (ISO 4406). That's already a lot, and since I used spectrometry for the analysis, the actual amount of silicon present could be up to 4-5 times higher. In combination with a large amount of iron also present in the analysis, it was clear that the bearing was wearing out due to contamination.

We also determined that the oil was severely and prematurely oxidized. There were a few likely culprits for this: silicon and iron do indeed act as oxidation catalysts, but there was another process at work here too: heat. The point of entry for contamination introduced silica dust directly into the hot process and tight clearances of the compressor, dramatically concentrating the load. This in turn lead to tiny super-heated spots within the system, which ultimately led to extremely rapid oxidation of the oil.

Enough Blame to Go Around

I went into the meeting with these findings and began by asking a simple question: Did anyone inspect the hose between the inlet air filter and the air end? As we've already established, I had reason to believe that it had cracks in it.

The people in the room began looking at one another other to see if anyone had. A member of the maintenance team pulled out his phone and showed me a picture for the crack in the hose and informed me that he'd reported it two weeks before the failure mode had been indicated, but no one had taken any action to resolve it.

Immediately, the planning team fired back that he should have told them it was urgent, since they didn't have enough time to scan through the reports and emails… and within minutes the Four B's process started. If you're unfamiliar with the "Four B's" process, it's a pretty simple concept: Blame maintenance, Blame operations, Blame planning, Blame the OEM - Blame anybody.

One of the utility engineers tried to break out of the blaming process by saying he wasn't convinced that normal dust could do

Image 1

Image 2

Image 3

so much damage, which worked. Everyone turned to me, waiting for an explanation. Because this is a concept I'm so familiar with, I was somewhat in shock that they would say this, and waited for a moment to see if someone would laugh and say, "just joking."

It wasn't a joke. They were serious. Fortunately I was able to explain how these tiny particles could cause so much trouble, they accepted that it was possible, and we were eventually able to have a productive discussion about a risk mitigation action plan.

What can we learn?

First, know this: Training is a necessity. You can have the best maintenance crew, but if you don't train them properly they're doomed to fail. Even after you train them properly, you still need to enable them to do their job via inspection preparedness (Inspection 2.0). In the case of our steel mill, the maintenance team member observed the crack and even took a picture of it but didn't have the knowledge to understand its criticality and the potential impacts of the failure mode it caused. This was due first and foremost to lack of training.

The planning team and the maintenance supervisor also didn't have clear protocols and organization in place to scan through the backlog of feedback from the PM tasks that had been performed. Implementing a systematic review of completed work orders would ensure that critical information isn't missed.

In short, reliability requires a multi-faceted, plant-wide culture change initiative. This will help ensure buy-in throughout the plant and help each team member to be properly enabled to contribute effectively to plant reliability.

The Mitigation Plan

As the meeting continued, we discussed possible strategies to mitigate future risk and, more immediately, to extend the failing compressor's life sufficiently to reach the next planned shutdown. The final strategy included high-efficiency depth filtration and an oil bleed and feed, as well as regular condition monitoring to track the machine's failure progress.

Filtering the oil did buy us some time, and adding fresh oil helped us to operate the air compressor for the eight weeks the teams needed to reach the planned shutdown, at which point we overhauled the machine and replaced the damaged air end bearings.

Failure is Your Best Teacher

I was raised in an engineering family. My father was one of the very first technology leaders to begin teaching people about vibration analyzers in 1989 in Cairo by selling them and training his customers. He taught me early in my life that my failures were even more important than my successes. I remember that after I returned home from a math test with some mistakes, he told me that it didn't matter what I did right. What mattered was the mistakes I made, because those were the things I didn't know and needed to learn. Those mistakes were my room to grow and my opportunity to evolve.

Now What?

After a failure, it's very important to inspect the damaged parts. This is a step many reliability engineers forget to do. Even worse, some consciously ignore it. Failed parts provide a wealth of information about what happened, and if they're not examined it's pretty likely that soon you'll start building a collection of similar failures to display on your office shelf.

The pictures to the left show the following:

1. Image 1: The small pitting visible here are the type of marks that prove that contamination is present.
2. Image 2: The heavily pitted area on the inner race shows where the contamination developed deep spalls and began to form a fracture network. This eventually developed into a complete fracture through the part to the outer race.
3. Image 3: there for the rollers….

The case study we've looked at helps us draw several conclusions.

Early on, we established the importance of designing your maintenance program on a solid foundation of accurate reliability data. We also learned that CM is one of the best tools we can use when striving for effective asset management. Having a timely and accurate understanding of your machine operation and failure modes is the best way to determine the correct combination of activities (PM, CBM, inspection tasks, etc.) that conforms to the apex of the P-F curve and helps us reach a tangible machine life extension.

Above all, we learned that proper training is the single most important investment we can make in our team. Training encourages educated observations and decisions, as well as promoting the culture changes needed to enable your teams' work in the plant. Training is your plant's golden parachute, giving you the ability to plan for and maneuver around costly failures you used to just endure.

In short, a well-educated, enabled, and organized team with a proper reliability culture will save a lot of unnecessary costs. ***ML***

Paul Farless | Noria Corporation

Factor: S1P

Lubricant Water Handling Ability: **Why it Matters**

More about this ASCEND™ Factor

Factor:
S1P — Lubricant Selection Process
Level:
Platform (P)
Stage:
Lubricant Selection
About:
Lubricant selection is a paramount first step, but many factors such as machinery requirements, operational context, available technologies, environmental impact, energy consumption and technological advances must be considered beforehand.

No matter the product being manufactured, I would say most facilities have some sort of water being introduced during the process. Some of the uses for water in the manufacturing processes include washing, diluting, transporting, cooling, etc. Knowing that these processes involve water, we often recommend that the lubricant purchaser considers a lubricant's ability to handle or resist water; what follows is a few reasons why.

Effects of Water Contamination in a Lubricant

Rust and Corrosion — Water induces oxidation which produces rust when in contact with iron and steel surfaces for extended amounts of time. Rust can cause abrasive wear, which is when a hard, rough surface slides across a softer surface. Once an oil starts to oxidize, you may see an increase in the acid number as well.

Hydrogen Embrittlement — This is when water finds its way into the microscopic cracks in the metal surfaces of the component. When water is introduced to excessive pressure, it will actually decompose into its components, and the hydrogen will be released. This can force those microscopic cracks to open wider, making them larger and thus more dangerous to the machine.

Cavitation — Vaporous cavitation is when the vapor pressure of water is met in a low-pressure area of the machine, which induces expansion of the vapor bubbles. Eventually, this expansion will cause the vapor bubbles to implode and condense back to the liquid state. When this occurs, it causes a sort of micro-jet that causes surface fatigue and erosion.

Lubricant Degradation — Water not only accelerates oxidation of metal surfaces, but also of the oil by depleting oxidation inhibitors and demulsifiers within the lubricant. When oxidation occurs, acid formation can occur soon after. There is also the obvious change in viscosity which is the most important factor of any lubricating oil. Add water to any other fluid, and the viscosity will decrease when hydrolyzed;

conversely, if the water is emulsified into the oil, it can produce sludge, which will actually increase the viscosity.

Decreased Load Carrying Capacity — In the presence of water, the film strength of the oil becomes impaired. The pressure-viscosity coefficient is disrupted, which means the lubricant's ability to solidify or increase viscosity in relation to load is impaired, and the appropriate lubricating film may not be produced. Water is extremely detrimental to this process within the lubricant.

Important Properties for Lubricant Selection in the Presence of Water

Base Oil — As previously mentioned, hydrolysis is the degradation of the base oil's molecules due to water. Hydrophilic polyglycols and some esters readily absorb water without any mechanical action needed. However, others like mineral, polyalphaolefins, silicone and PFAE require a mechanical action by the lubricated part to cause water absorption and the formation of a water-oil emulsion. Be sure to take this into account when selecting a water-resistant lubricant.

Demulsibility — When selecting a lubricant that needs to be highly resistant to water, one property that needs to be taken into account is demulsibility. Demulsibility is a lubricant's ability to release water. Most of the paper mills, food-processing facilities and steel mill operations that I have encountered in the field often incorporate a lot of water into their processes. Most of our recommendations to these types of facilities are centered around water resistance and demulsibility.

Thickeners (Grease) — Grease is normally chosen where adhesion properties are required. But, if a grease absorbs water, it becomes softer, loses adhesion, and washes out of the lubricated part. In greases, there are certain types of thickeners that allow for better water resistance. It is commonly known among industry specialists that aluminum and sulfonate greases are particularly water-resistant.

Hydrolytic Stability — Hydrolytic stability is the resistance of a cured polymer material to reverting to a semisolid or liquid form when exposed to high humidity and temperatures. Generally, a lubricant will perform better in wet/humid or high-temperature environments when it has good hydrolytic stability.

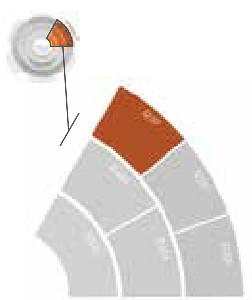
Although I have pointed out a few ways to assist in lubricant selection in the presence of water, I would like to conclude by saying that the main factor in any of this is preventing water contamination and keeping all other types of contamination to an absolute minimum. Fitting leaks are high on the list of reasons why water ingression exists in a machine. This is why we advise against the use of Teflon tape, and instead recommend using a thread sealant like PLS 2 to prevent micro leaks. Lastly, when preventing contaminant ingression, we highly recommend modifying machinery with preventative measures such as desiccant breathers and quick connects. ***ML***

About the Author

Paul Farless is an industrial service technician for Noria Corporation. His duties include collecting data and preparing reports for the engineering team. Prior to joining Noria, Paul worked as an automotive maintenance technician for an auto-repair service company. He also served four years in the U.S. Navy as a gunner's mate third-class petty officer and as a seaman deckhand, where he was responsible for the troubleshooting and maintenance of electromechanical and hydraulic systems. A detail-oriented team player, Paul works well in fast-paced environments and uses his military background to excel and maximize efficiency.

How to Work with Your Lubrication Supplier
to Establish a Quality Control Process

More about this ASCEND™ Factor



Factor:
R1P— Quality Control Process
Level:
Platform (P)
Stage:
Lubricant Reception And Storage
About:
The quality control process for new lubricants should be formed in collaboration with the lubricant suppliers and should establish a methodology with which lubricant characteristics can be inspected and evaluated.

When manufacturing plants receive raw materials on their dock, there is usually a rigorous quality control process in place to check these materials before they are sent to the production lines. Companies pay good money for these materials, and they expect them to be in good condition in order to ensure there are no manufacturing flaws in the end product. Do lubricants at your site receive the same amount of attention when they are received? With the price of lubricants being so high and the expectation for them to perform (often under extreme circumstances), shouldn't they have a quality control process of their own? Just like faulty raw materials create flawed products, less than ideal lubricants can increase the chance of machine failure.

Creating a Quality Control Process

The first step when starting a Quality Control Process is to list out the goals of the program: what are you trying to accomplish, and what tests are you going to use to verify success? Is the program going to go as far as performing in-depth oil analysis on incoming lubricants, or are you just going to physically inspect the deliveries?

Typical steps in a Quality Control Process

Receiving Times — Make sure all lubricants are received in the agreed-upon amount of time. This step doesn't check the quality of the lubricants themselves but instead shows the quality of the supplier. If a single delivery is a bit late, it can probably be excused; but if deliveries are consistently late, you might think about switching suppliers.

Accompanying Documents — When setting up an original agreement with the lubricant supplier, some companies request that a Quality Certificate or Certificate of Analysis be brought when lubricants are delivered. This document includes details such as when a sample was pulled, the analysis of the additives and the particle count. Other documents, such as a record of the last time the blending plant or supplier was audited, might also be requested.

Visual Inspection — Ensure the correct lubricant is being delivered in the right container/size. Check the container's bungs, caps or seals to make sure there are no points for possible contamination. Check the label to make sure the correct lubricant is being received, that the lubricant is not out of date, and that it falls in line with the shelf life of the Q.C. program. If bulk lubricants are being delivered and offloaded via a pump, all lubricant transfer equipment should be inspected to ensure that it was properly stored and to make sure you will not be introducing contaminants into the lubricant. All transfer equipment should also be flushed before they deliver lubricants to the bulk tank. Bulk deliveries should always have a sample taken to confirm properties with lab testing.

Oil Analysis — Depending on the volume of lubricants and overall machine criticality, a site may want to perform oil analysis on all incoming lubricants. Testing may be done on-site or sent to a laboratory for more in-depth testing. A couple of on-site tests that can be performed are:

- Viscosity — An easy test that can be done on-site with a relatively inexpensive tool called a visgauge. Viscosity is the single most important property of a lubricant; if the delivered lubricant is not the correct viscosity, it should be returned.
- Particle Count — On-site particle counters are becoming a common tool for lubrication programs these days. Within a couple of minutes, you can get a report on how clean or dirty the tested lubricant is. Remember, just because the oil is new doesn't mean the oil is clean.

What to do with lubricants that fail

Listing actions that should be taken when lubricants fail any of the tests you put them through is important to close the circle of the quality process. These steps should be created in collaboration with your vendor and should be clearly defined based on the test that the lubricant failed. Commonly, once a lubricant is rejected, we should receive a replacement lubricant within a specified timeframe to help avoid using the failed product. *ML*

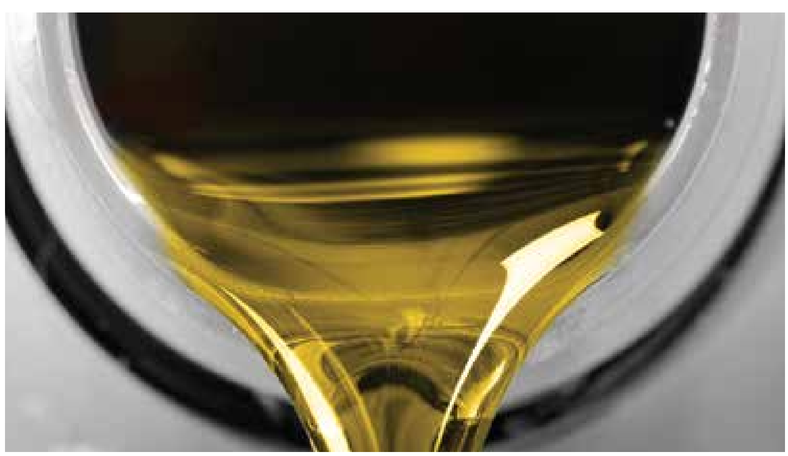
About the Author

Travis Richardson is a technical consultant for Noria Corporation. He holds a Level II Machine Lubrication Technician (MLT) certification and a Level III Machine Lubricant Analyst (MLA) certification through the International Council for Machinery Lubrication (ICML). Contact Travis at trichardson@noria.com.

The "Lube-Tips" section of *Machinery Lubrication* magazine features innovative ideas submitted by our readers.

Who is Lubricating Your Machinery?

When lubricants are accessible to practically anyone in a company, lubrication-related problems are bound to develop. Inexperienced personnel could use improper lubricants and/or procedures or apply the lubricants at the wrong time, throwing off the lubrication schedule.



Oil Quality Matters

Oil quality is established by the refining processes, and additives are most effective if the oil is well refined. Although the overall performance of an oil can be improved by introducing additives, a poor-quality oil cannot be converted into a premium quality oil by introducing additives.

Keep Bearings Clean

To keep dirt out of greased bearings while relubricating, use a three-pronged approach:

1. Use plastic caps that fit over the grease fittings to keep contamination out.
2. Use a lint-free cloth or clean rag to wipe down the fitting prior to greasing.
3. Use Saran Wrap or some other type of clinging cooking wrap to cover the end of the grease gun when it is not being used. ***ML***

Did You Know?

Additional tips can be found in our Lube-Tips email newsletter. To receive the Lube-Tips newsletter, subscribe now at

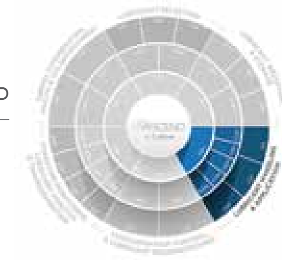
MachineryLubrication.com.

Have Some Tips?

If you have a tip to share, email it to editor@noria.com.

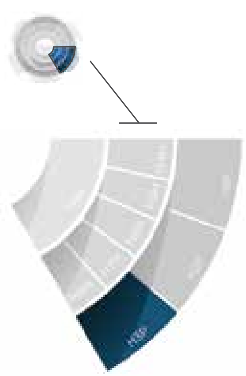
Paul Farless | Noria Corporation

Factor: H3P



A Guide to Storing **Spare Equipment**

More about this **ASCEND™ Factor**



Factor:
H3P – Handling and Application Devices

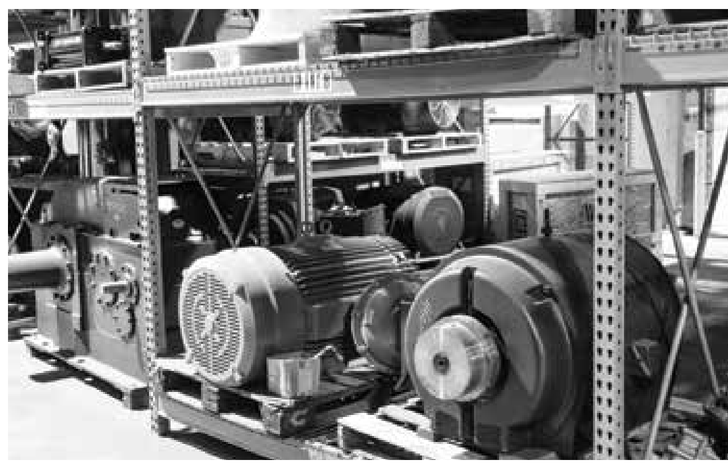
Level:
Platform (P)

Stage:
Lubricant Handling & Application

About:
Setting and defining goals clarifies a lubrication program's objectives, and implementing rewards systems encourages staff to reach those goals.

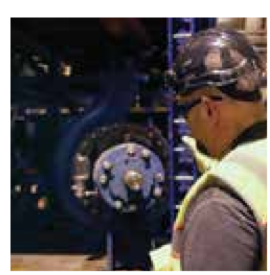
In the industrial space, it is often a good practice to store spare equipment. Generally, the more critical a piece of equipment is, the more important it is to keep a spare or two on hand; some facilities proactively store a spare or multiple spares of all their lubricated and rotating machinery: bearings, gearboxes, pumps, blowers; the whole nine yards.

Storing spares is a good proactive measure to ensure that downtime is minimized in the plant. After all, that's what we are all worried about here: keeping the plant running. So, this will act as a soft guide on some best practice methods to store equipment, how to lubricate the stored equipment and why we want to use specific types of lubricants when storing this equipment.



Reception and Handling —

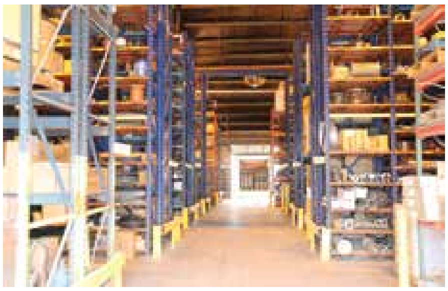
First and foremost, we need to consider safety when receiving, handling, and storing the spare equipment. The technicians need to utilize the proper equipment and techniques when handling the equipment. Furthermore, as with receiving and handling lubricants, the best practice is to set reception and handling standards. Just like with new lubricants, there must be quality assurance and quality control standards to ensure that you are receiving the correct equipment: size, HP, Modified/Not Modified, etc., must be accounted for.



Inspection and Cleaning —

Upon inspection, depending

on the piece of equipment, the receiving technician should take a quick look into the headspace, taking note of any manufacturing debris or otherwise harmful contaminants that may have entered the headspace during manufacturing. If any



debris is found, then most facilities prefer doing a flush with a low viscosity flushing oil that is compatible with the in-service lubricant. In machinery lubrication, the number one goal is to keep any and all contaminants out of the machine or bearing, even if it doesn't have lubrication when it arrives at the facility. This is an especially important step.

Storage Space —

Just like lubricant storage and handling, you want to make sure of a few key factors when it comes to the space in which the equipment is being stored. Preferably, the storage space is dedicated just to stored equipment. Secondly, the space needs to be climate controlled if at all possible. Just like a lube room, we want the space to be clean, organized and at a maintainable temperature. If at all possible, there needs to be spill containment and fire extinguishing capabilities, whether that is a couple of extinguishers on the wall or a room with a pre-existing sprinkler system. Most storage spaces aren't a high risk for fires, but in the industrial world, ANYTHING is possible. Remember, this is an explanation of best practice or the ideal way of storing. I like to think of it as best-effort rather than best practice because sometimes best practice isn't all that practical with what each facility has on hand.

Storage Lubricants —

There are many different storable components to consider when deciding if it needs to be stored with lubricant in it or not. Some machines come pre-lubricated from the manufacturer; some don't. The best thing to do is to look at the OEM manual and find out the OEM recommended lubricant for that specific machine or bearing. Most of the time, the manual will also give recommendations on how to store this piece of equipment. The best thing to do is follow that recommendation, but if there is no OEM recommendation, there are certain ways to store oiled components versus greased ones:

- **Oiled Components** — Cleanliness is paramount. Grease can handle certain contaminants better than oil, so making sure that the oiled component is clean, flushed and completely plugged during storage is important. There is no telling how long some of this equipment will be stored. The primary concern is the headspace of the unit; either fill it to the top with oil or utilize what is known as a vapor phase corrosion inhibitor (VPCI). This will help prevent corrosion caused by oxidation. However, if you fill it all the way, be sure to inspect around the seals and plugs to ensure there is no leakage.
- **Greased Components** — Commonly, people think that lithium grease has a shelf life of twelve months, which in most cases is probably pretty close. But what about the grease that is in stored equipment? Generally, it is best practice to clean and ensure that no contaminants can make their way into the bearings, but bearings are usually pretty tough.

No matter if it is a greased or oiled component, when the item is stored we'll want to periodically rotate the shafts or race to keep the additives from settling in the oiled components. We want to keep the grease from bleeding from the greased components. This is why spill containment, fireproofing and climate control are so important for storing spare equipment; it's all about lubrication excellence. ***ML***

About the Author

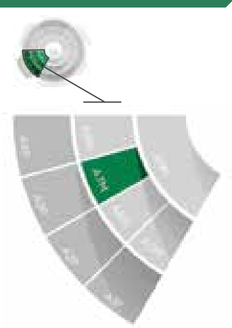
Paul Farless is an industrial service technician for Noria Corporation. His duties include collecting data and preparing reports for the engineering team. Prior to joining Noria, Paul worked as an automotive maintenance technician for an auto-repair service company. He also served four years in the U.S. Navy as a gunner's mate third-class petty officer and as a seaman deckhand, where he was responsible for the troubleshooting and maintenance of electromechanical and hydraulic systems. A detail-oriented team player, Paul works well in fast-paced environments and uses his military background to excel and maximize efficiency.

Jeremie Edwards | Noria Corporation

Factor: A7M

Demystifying Oil Analysis

More about this
ASCEND™ Factor



Factor:
A7M – Troubleshooting and Root Cause Analysis

Level:
Management & Training (M)

Stage:
Condition Monitoring, Lubricant Analysis and Troubleshooting

About:
The right approach to troubleshooting and root cause analysis is critical to diagnosing problems quickly and finding sustainable solutions.

Oil analysis is a touchy subject for some people. I have been to places where reading an oil analysis report was viewed about the same as reading tea leaves; other places treat oil analysis like a religion. The true nature of oil analysis is somewhere in between. It is one of the many tools that reliability folks should be familiar with since it is meant to be a window into how our equipment is wearing, what type of stuff is getting into our equipment and if any of the contamination detected is hurting the machine or the oil.

A lot of the places I go to are doing some type of oil analysis, or at least attempting it. I often find that samples are being pulled from equipment and getting shipped out for analysis, but nothing is being done with the results. One recent site visit revealed that only one piece of equipment was having oil samples pulled, but nobody knew who was pulling the sample, where the sample was pulled from, who was getting the results or anything else. It is hard to say you are performing oil analysis if you don't know who is doing it or how it is being done. Maybe it's time to demystify oil analysis a bit.

First things first: before we can even think about what we want to learn from our oil, we need to find out what our oil is supposed to look like. So, when oil first shows up on-site, make sure you pull a sample and run a couple of tests. Since we don't necessarily know what kind of information we will be looking for in the future, it is a good idea to run a few different tests. Fourier Transform Infrared Spectroscopy (FTIR) and Elemental Spectroscopy are great places to start. The results from these two tests will set you up for success later on when you're trying to figure out what is going on in your equipment.

Since we now have that initial sample, also known as our "baseline" sample, we can look at what we want to learn from our oil. There are three major categories that people typically think about when it comes to oil analysis:

1. The condition of the oil.
2. The contaminants in the oil.
3. The wear taking place in the machine.

Whether or not you need to know all three things from your oil is a bit of a complicated question. Let's say that you have a very small gearbox that only holds around a quart of oil. Oil analysis may or may not be warranted on this gearbox; it all depends on how critical this little gearbox is to operations. If this gearbox could shut down an entire facility by failing, then it is probably a good idea to do some analysis on it. For argument's sake, let's say that this gearbox has the power to shut the whole place down if it goes out.

So, what type of oil analysis should we do on it?

Well, the oil volume isn't large, so the cost of an oil change shouldn't be too bad. This means that information about the oil's condition may not be high on our priority list.

How about contaminants?

Certainly, solid particles would be of interest. These are the ones that cause a lot of mechanical wear with three-body abrasion. Something as routine as a particle count would be a good idea, even with this small volume of lubricant.

Machine condition?

Absolutely! Machine condition would be the number one reason to perform oil analysis on this gearbox. Even if you don't care about the condition of the oil or have little thoughts as to the contaminants getting in there; if this gearbox can shut the entire place down, you definitely want to know what kind of wear is taking place inside of it (not to mention how much wear).

Now that we know the type of information we want to gain, what tests should we run? Since we want to know more about the wear of the machine components, we need to look for what those components are made from. Firstly, ferrous density is going to tell us the concentration of ferrous metals. This is an excellent resource since components are typically made with such metals.

A step further is analytical ferrography. Analytical ferrography can be done in a lab with a technician looking at the actual wear metal's particles. These technicians are highly trained and can offer insight as to what type of wear is taking place — an extremely handy tool for figuring out how healthy the machine is.

Last but not least is elemental spectroscopy. Unlike FTIR (which looks for compounds), elemental spectroscopy looks for elements (or the building blocks). This can be a fantastic tool, especially if you are familiar with the types of metals that exist within your equipment, particularly in the given components (like the bearing material, if there are babbitt materials). If I know that a particular gearbox is a worm drive and I see signs of copper, lead or bronze on my elemental analysis report, I know where those elements are coming from. This goes a long way in telling me how much wear has taken place.

Now let's move on to a large hydraulic reservoir. This system isn't mission-critical; no catastrophic failures will be caused if this system goes down, but the system holds a lot of high-dollar fluid in it. My focus switches a bit: I am no longer quite as interested in the wear metals as I am in the health of the oil. I mean, if it costs thousands of dollars just to change the oil in this system, I should probably try to get as much life out of that oil as possible. So, what information do we want from this system?

Since the fluid is the part we are worried about, we need to look at the physical and chemical properties of the oil. We need to ask ourselves:

What is the most important property of a hydraulic fluid?

The viscosity of the fluid. Since the fluid is doing the work, we need to make sure that it is still the right viscosity.

What are some of the things that influence viscosity?

Acid/base number influences viscosity, so it's a good idea to keep tabs on these. Oxidation also influences viscosity; this is where that FTIR comes in handy.

What other desirable things are in the oil?

Our additives. These typically show themselves in either the FTIR or Elemental Spectroscopy. Good thing we thought ahead and got that baseline of the oil as it came in, right?

How about all of the outside factors? We know about the debris that gets generated within the machine from the work it does. We know about the health of the lubricant, the chemical and physical properties. The one thing we haven't touched on a whole lot is the stuff getting into the oil/equipment that we aren't putting in there on purpose: the contaminants.

The contaminants are going to affect both the oil and the equipment, and none of it in a good way. So we need to look at what types of contaminants are being introduced to our equipment/lubricants.

Does this piece of equipment breath through the headspace (does the oil level fluctuate depending on cylinder movement or operating conditions)? If it does, at the very least we need to look at particles and probably moisture as well. The cleaner and drier the oil, the longer it will last, and we have a lot lower likelihood of having early failures. Particle counts and moisture levels are key, and both are easily detected by and commonly included with FTIR and elemental spectroscopy. (Seriously, those two tests are staples in oil analysis for a reason.)

Maybe you want to get hands-on with testing for contaminants, and you are trying to go the extra distance. Patch testing is a fairly simple concept and lets you look at the contaminants yourself so you can see exactly what is going on.

Now, if you are looking at motor oils, you might have a bit of a different concern, especially with older equipment that might have a bit of wear but a lot of life left. Usually, one of the biggest worries is blow-by or getting a bit of fuel into your oil. This would typically show itself as a change of viscosity or a change in aroma. Something that could be a bit more worrisome is the flash point. Depending on the application, this could be a safety concern as well.

Keep in mind that this is not an exhaustive list of tests available but more of an introduction and an explanation as to why one test might be more relevant to your situation. The real takeaway should be the answer to this question: "What do I want to learn and what is important for this piece of equipment?" ***ML***

About the Author

Jeremie Edwards is an Associate Technical Consultant at Noria Corporation. He is one of an elite few certified by the International Council for Machinery Lubrication (ICML) as a Machinery Lubrication Engineer (MLE) and did so in order to become the best advisor for clients when it comes to their continuing education needs. Before joining Noria, Jeremie served six years in the U.S. Army as a parachute rigger and was deployed in Afghanistan, Uzbekistan, Turkey and Germany.

Ray Garvey, Matthew Fergusson and Mike Rostosky

Why Equipment Fails And **What You Can Do To Prevent It**

"Unplanned repairs and unplanned downtime are ten times more expensive than planned repairs."

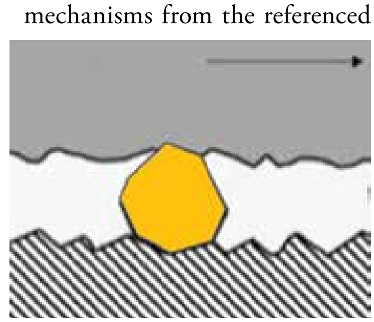
Unplanned repairs and unplanned downtime are ten times more expensive than planned repairs and planned downtime. In addition to being expensive, unplanned downtime is unproductive, disruptive, distracting and sometimes causes collateral damage. Planned is manageable; unplanned is not.

Planning repairs to equipment requires advance notice months before critical components fail. To this end, one must understand the following:

- Why do equipment components fail?
- What are likely failure mechanisms for those components?
- What are the factors that initiate and accelerate the failure mechanisms?
- What are factors that mitigate or avoid the failure mechanisms?
- What proactive condition monitoring methods can identify contributing factors that accelerate failure mechanisms?
- What predictive condition monitoring methods can measure failure progression from incipient to catastrophic?

Failure Mechanisms

Abrasion, adhesion, fatigue, electric discharge, corrosion and deposition are common failure mechanisms from the referenced literature. Characteristics of these failure mechanisms are listed in Table 1 and described below.



Abrasion affects nearly all mechanical systems. It begins when silica dust particles are transported by the lubricant to a narrow clearance between moving surfaces. Hard particles that are too large to pass through become embedded into one surface and cut the other. The shear force between the lubricated hard particles and the moving surface cut a V-notch into the moving metal surface.

This cutting process emits a spectrum of mechanical vibration

FAILURE MECHANISM	AFFECTING COMPONENTS	CONTRIBUTING FACTORS	MITIGATING FACTORS
Abrasion	Mechanical	Dust contamination, System Sure, Defective breather	Contamination control, clean, dry, fit for use
Adhesion	Mechanical	Lubricant misapplication, slow speed, excess load, low viscosity	Lubrication, speed, load, viscosity
Fatigue	Rotating, vibrating, flexing	Elevated dynamic loading	Minimize dynamic loading
Rolling Fatigue	Bearings, gears	High dynamic load improper fit	Minimize dynamic loading
Bending Fatigue	Shafts, joints, fasteners, structures	Sharp fillet or other tensile stress concen-tration	Pre-stressed compression, fracture-tough-ness, fillet radius
Cavitation Fatigue	Impellers, pumps, valves, piping	Speed, pressure, and flow extremes	Speed control, fluid dynamics, and surface treatment
Electric Discharge	Mechanical, electrical, inductive, static	Shaft currents, moisture, round faults, deterioration, looseness, corrosion	Grounding, contamination control clean, dry, fit for use
Corrosion	Mechanical, electrical	Water or other corrosive contamination non-desiccating breather	Contamination control, clean, dry, fit for use
Stress Corrosion	Shafts, joints, fasteners, structures	Sharp fillet or other tensile stress concen-tration	Pre-stressed compression, surface seal, fracture-toughness, fillet radius
Galvanic Corrosion	Structures, fasteners, electrical and mechanical	Electrolyte between dissimilar metals such as carbon and stainless steel	Insulate between dissimilar metals
Erosion Corrosion	Impellers, pumps, valves, piping	Corrosive fluid with eroding flow	Seal/protect surfaces
Deposition	Flow controls, filters, screens, valves, fans	Temperature cycles, polar constituents, static charge	Awareness & prevention

Table 1. Common failure mechanisms, components, contributing factors and mitigating factors.

from the point of abrasion and generates abrasive wear debris, which is carried away by the lubricant. This mechanism generally is not self-propagating and is easily offset by contamination control. It can be triggered by a surge in the circulating system or by a defective breather.

Adhesion (or boundary wear) impacts nearly all mechanical systems with loaded components. Adhesive wear and other boundary wear damage is progressive and self-propagating while also accelerating corrosion. Metal-to-metal contact occurs when the lubricant film (designed to eliminate friction and separate a roller from a race or a journal from a shaft) fails due to inadequate lubrication. The increase in friction and shear causes mixed and boundary lubrication regimes.

The contact emits stress waves. Compression with mixed and boundary lubrication leads to shear and friction, which results in intense heating, melting and discoloration.

Metal debris and oxides are released into the lubricant, and a spectrum of vibration is emitted. This mechanism can be prevented by maintaining the proper lubricant at the correct level and by operating at the designed speed and load. It may be triggered by a slow speed, high load, low viscosity or inadequate lubricant delivery.

Rolling Fatigue (also called Hertzian fatigue) affects mechanical systems with loaded bearings and gears. Roller bearings and gears often fail due to the process of rolling contact, which eventually leads to material fatigue cracks and spalling. Compression between the rollers and races and between gear teeth produces subsurface

Hertzian contact shear that eventually work-hardens the metal until microcracks form, grow, interconnect and then release metal debris. Rolling impacts at spall and other surface defects magnify stress waves and release more debris into the lubricant. Fatigue can be offset by minimizing dynamic loading from imbalance, misalignment and resonance, as well as by static load reduction and other maintenance practices; it can be triggered by an improper fit or thermal growth.

Bending Fatigue affects shafts, joints, fasteners and structures. Cyclic bending produces fatigue cracks originating from surface defects in the vicinity of tensile stress concentrations.

Contributing factors include sharp fillet radius, material flaws and geometric stress concentration sites. Mitigating factors may include pre-stressed compression, use of materials with high fracture toughness and smooth fillet radius.

Cavitation Fatigue failure mechanisms typically occur on impellers, pumps, valves and other flow devices. Cavitation fatigue involves cyclic void collapse shock waves that cause sub-surface fatigue cracking, pitting and spalling. Contributing factors include extreme variations in speed, pressure and flow. Mitigating factors include speed control, fluid dynamics and surface treatments.

Liquid cavitation is stimulated by pressure variations in the cyclic fluid flow near the surface. In a slow part of the pressure cycle, suction enables evacuated micelle nucleation originating from solid surface irregularities. Highly saturated dissolved gas from the surrounding liquid may diffuse into expanding bubbles. Later in the pressure cycle, suction is released, and the bubbles implode back toward the nucleation surface irregularities. The implosion causes a supersonic surface impulse and transfers compression and shear stress waves. Shear from the stress wave dislocates subsurface

material morphology. Eventually, these dislocations lead to fatigue cracks and spalling.

Note that when the bubbles contain partial pressure gases diffused from the surrounding liquid, there is also intense heating from the compressed gases. Cavitation damage, which normally is progressive and self-propagating, often results in fatigue cracking and stress corrosion cracking. It is triggered by pressure, flow and speed variation but can be offset by fluid flow design, control, speed and surface treatment.

Erosion can affect valves, pipes, baffles, impellers and other electrical and mechanical components exposed to streaming particulate matter. It occurs when high-velocity liquid or solid matter impacts a solid surface, causing intense points of compression and resulting in deformation and shear. Stress waves are emitted from the impact points, and debris is dislodged from the damaged surface. This failure mechanism can be prevented by protecting surfaces with energy-absorbing coatings.

Electric discharge affects electrical components and inductive or static charged mechanical components with voltage. The potential to ground applies an electric field through a medium. Electrons and ions accelerate via spark, track, arc plasma.

Arc-spark events yield a wide spectrum of mechanical and electrical energy.

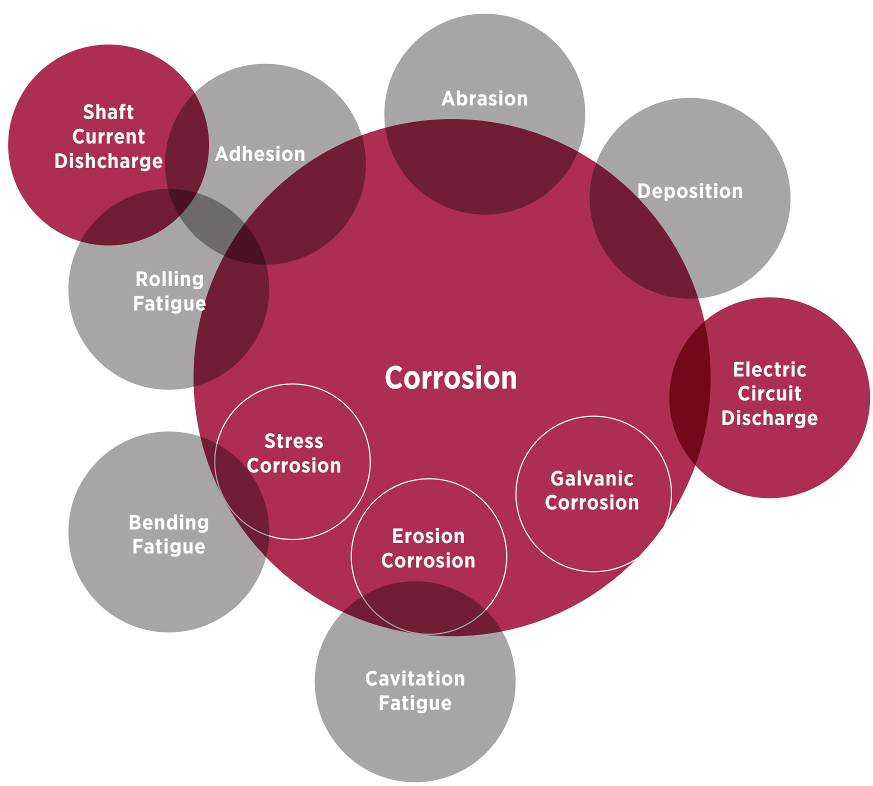


Figure 1.

Measurrement Method	Proactive Detect Root Cause	Predictive Quantify Failure in Progress
Vibration	Balancing Alignment	Roller/gear defects Failure progression
Oil	Contamination control Adequate lubrication	Ferrous debris Particle shape classification
Thermal	Normal lines Normal connects	Electrical faults Mechanical adhesion
Motion	Acceptable resonance Acceptable timing	Synchronous resonance Timing faults
Spark	Survey motor shaft brushes Survey before entry	Low voltage spark events High voltage are events
Inspect	Preventive maintenance Quality control	Substance deposition Procedure misapplication

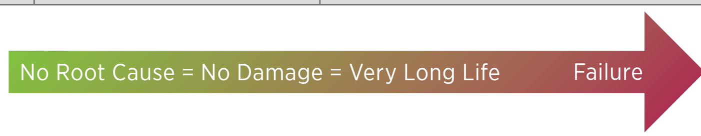


Table 2: Condition monitoring techniques to monitor failure mechanisms and root causes.

Surface morphologies undergo surface erosion leading to heat damage. An electric discharge ionizes proximate matter to form a discharge or plasma track.

Contributing factors include moisture, degraded insulation, ground faults, looseness, corroded contacts and contamination. Mitigating factors include clean and dry materials and compartments.

Corrosion impacts almost all electrical and mechanical systems and is synergistic with all other failure mechanisms. It occurs when a corrosive substance attacks metal and changes the surface from strong, thermally and electrically conductive metal into soft, electrically and thermally resistive oxide.

The resulting oxide is easily rubbed off by shear, which exposes fresh metal for sustained oxidation. Mild rubbing emits stress waves and spreads soft metal oxides into the lubricant, exposing metal to the oxidation process. This mechanism may be prevented by moisture contamination control. It can be triggered by process contamination, a coolant leak or a defective desiccant breather.

Three synergistic combinations of corrosion with tensile stress, galvanic current and erosion are identified below.

Stress corrosion affects shafts, joints, fasteners and structures. This synergistic combination of tensile stress and corrosion produces intergranular corrosion accompanied by tensile fracturing, which progressively self-propagates.

Contributing factors include sharp fillet radius, corrosive substance and stress concentration. Mitigating factors include pre-stressed compression, surface sealing and material fracture toughness.

Galvanic corrosion affects structures, fasteners, electrical and mechanical components. This occurs when an electrochemical corrosion corrosive substance couples a noble cathode, such as stainless steel, with a less noble anode, such as carbon steel.

Contributing factors include the presence of corrosive substances together with the electrical connection of more noble with less noble metals. Mitigating factors include insulating interfaces between dissimilar metals, protecting/coating/sealing surfaces, contamination control and visual inspection.

Erosion corrosion is an erosion process accompanied by a corrosive substance. Erosion removes oxidized surface material, exposing underlying metal for rapid and sustained oxidation. It affects impellers, pumps, valves and piping.

Contributing factors include corrosive fluid with eroding flow. Mitigating factors include providing surface protection or sealing.

Deposition results from a dysfunctional and progressive accumulation of foreign material on a critical electrical or mechanical component. Examples include precipitated varnish formation and accumulation on a control valve, fibrous material accumulation on a fan and polar substance accumulation on an electrical circuit.

Varnish accumulation on a control valve may lead to plugging and sticking, while fibrous material accumulations on a fan may cause imbalance and a potential fire risk. This failure mechanism can be prevented by detecting, interpreting and addressing the specific accumulation process. The corrective action plan should be specific to its characteristic process.

Interaction of corrosion and/or electric discharge mechanisms with the other failure mechanisms described above is synergistic, as portrayed in the Venn diagram in Figure 1.

Time-to-fail accelerates with interacting factors. Remaining useful life, e.g., incipient to catastrophic failure, shortens from decades to years, and even to months under these combined effects.

Corrosion and electric discharge

Figure 2

deteriorate surface morphology and destroy remaining useful life. Corrosion contributes to mechanisms of electric circuit discharge, deposition, abrasion, adhesion, rolling fatigue, bending fatigue and cavitation fatigue. Stress corrosion, erosion corrosion and galvanic corrosion mechanisms advance general corrosion rates by orders of magnitude. Electric discharge erosion reduces the capacity for surface metals to resist pitting from rolling fatigue.

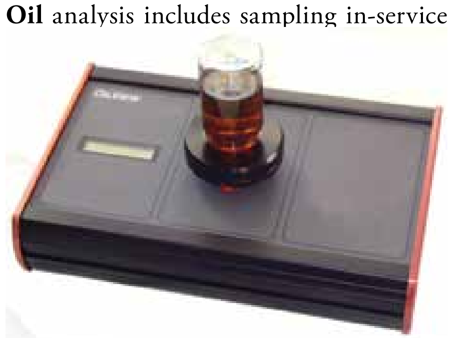
Condition Monitoring

Table 2 updates the table from the March 2003 Machinery Lubrication article, "How Machinery Wear Rates Impact Maintenance Priorities." This revised table demonstrates how vibration analysis, oil analysis, thermography, motion amplification, spark detection and visual inspection are complementary techniques to proactively evaluate root cause issues and predictively quantify failure mechanisms in progress.

Vibration monitoring and analysis employ a measurement configuration (maximum frequency of interest, sonic and ultrasonic frequency stress wave and heterodyne ultrasonic) appropriate for detecting and trending desired measurement information.

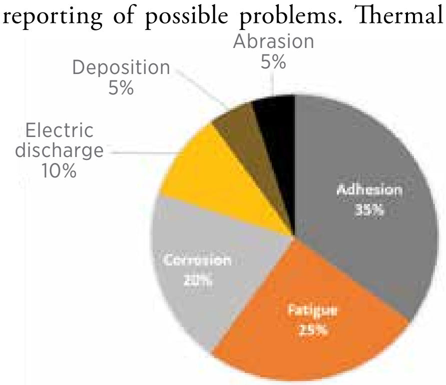
Machine vibration monitoring is often the core condition-based monitoring methodology for drives and driven rotating machinery. Proactive measurement of sinusoidal mechanical vibrations quantifies troublesome root cause issues such as misalignment, imbalance, looseness, and resonance and facilitates early detection and correction. Sonic and ultrasonic frequency range impact monitoring measures the progression of roller and gear defects. This predictive information is helpful to identify failing components, evaluate severity and schedule planned maintenance.

Oil analysis includes sampling in-service



lubricants and testing those samples to evaluate fluid chemistry, system contamination and machinery wear. Proactive monitoring for fluid condition and system contamination supports precision lubrication practices. Predictive monitoring for ferrous and nonferrous wear debris, together with particle shape classification, is helpful to identify failure mechanisms, evaluate severity and schedule planned maintenance. Oil and vibration analysis together are complementary, not redundant.

Thermal monitoring and analysis include single point, line-scanning and thermal imaging measurements. Proactive temperature scans are simple, quick and highly effective — finding something hot or cold that should not be, in comparison with surroundings or with similar mechanical and electrical components. Thermal images superimposed on respective visual images facilitate recognition, identification and reporting of possible problems. Thermal



monitoring is often the best condition monitoring technology to identify and predict potential failure points for electric power connection, transmission and distribution systems.

Motion monitoring and analysis include motion amplification, phase analysis, frequency analysis and amplitude analysis using video camera imaging. Proactive uses of motion amplification include monitoring and accepting structural resonance, mechanical timing and synchronous phasing. Motion monitoring, like thermal imaging, takes in thousands of measurements within a field of view

for quick identification and severity determination using non-intrusive surveillance. Problems with amplitude, timing and phase are observed, amplified and trended.

Spark monitoring and analysis include distinguishing and analyzing radio waves produced from arcs or sparks. Proactive uses of spark detection and analysis include a survey of motor bearings and a survey before opening an electrical enclosure. Predictive uses of spark detection and analysis include trending low voltage spark events and/or high voltage (>1000 V) arc events.

Inspect and test includes visual inspection with or without tools. Visual inspection is typically performed during walk-around vibration, oil, thermal, motion and spark monitoring, as well as during preventive and quality control procedures. These inspections proactively find and correct misapplication, contamination and incorrect adjustments. They predictively identify failure progression such as substance deposition or procedure misapplication.

Case Histories From A Mill

The mill has decades of experience with vibration analysis, oil analysis and lubrication. Team members are skilled and have very good tools, and the mill operates with about 97% availability.

Root Cause Failure Analysis (RCFA) reports included failed rolls, couplings, seals, bearings, forming wire, cooling tower, driveshafts, nozzle, screen, gears, retainers, switch and belt drives.

This figure represents failure mechanisms as a percentage of estimated RCFA production and RCFA estimated repair costs:

- Adhesion 35%
- Fatigue 25%
- Corrosion 20%
- Electric discharge 10%

The photograph in Figure 2 shows the shaft current electric discharge failure of a 600 HP motor bearing.

Continuous Improvement

Continuous Improvement based on facts, such as Root Cause Failure Analysis (RCFA) of planned and unplanned repairs, provides an opportunity for cost reduction and reliability improvement. The next step for continuous improvement based on RCFA history may call for expanding on-going condition monitoring to cover all the above-listed methodologies. Add the new condition monitoring methods, starting small; demonstrate success and grow to achieve desired continuous improvement objectives.

For example, continuous improvement to start-small-and-grow an active vibration analysis, thermography, motion amplification and preventive inspection condition monitoring program requires the addition of oil analysis and spark detection.

Start-Small-And-Grow Oil Analysis

If RCFAs indicate problematic fatigue and abrasion for bearings and gears, consider start-small-and-grow by using on-site oil analysis to monitor abnormal wear and water contamination.

When a ferrous density measurement reveals abnormal wear, use a magnet to retain the debris, and use a camera or microscope to view the debris on the sensor surface.

Start-Small- And-Grow Spark Detection

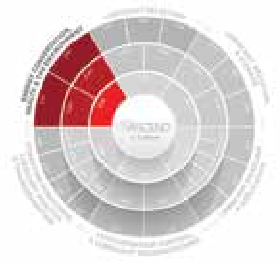
If RCFAs indicate issues with electric discharge causing damage to DC motor drives or other equipment, consider start-small-and-grow by using arc-spark measurement. For example, a Spark Data Collector with a radio wave sensory antenna uses peak-to-peak stress wave analysis to reveal spark events. Use this device to survey and locate faults. Follow up with periodic measurements to monitor, trend and gauge severity.

Conclusion

Common failure mechanisms include abrasion, adhesion, fatigue, electric discharge, corrosion and deposition. Mechanisms often progress in stages from incipient to catastrophic, to which component types each applies, factors that contribute and other factors that mitigate each mechanism.

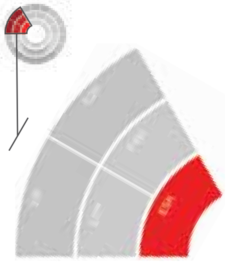
Rapid equipment failure occurs when galvanic corrosion, stress corrosion, erosion corrosion and electric discharge mechanisms denigrate surface morphology, synergistically accelerating progression from incipient to catastrophic under sustained effects of fatigue and adhesion mechanisms.

Proactive and predictive condition monitoring methods, including vibration, oil, thermal, motion, spark, and inspection are recommended to detect root cause contributing factors and to measure various stages of progressive failure. For example, start-small-and-grow a condition monitoring program already covering vibration, thermal, motion and inspection by adding on-site oil analysis with wear debris analysis and adding spark detection.
ML



Monitoring Consumption

More about this **ASCEND™ Factor**

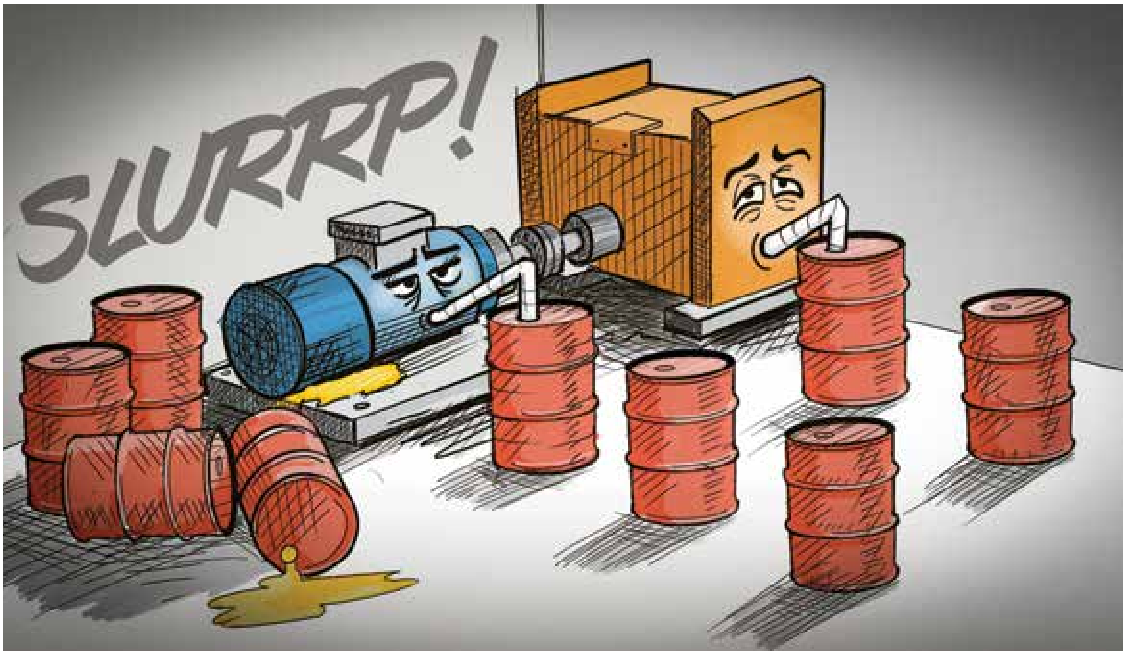


Factor:
E5K — Energy Conservation, Health & Environmental KPIs

Level:
KPI's (K)

Stage:
Energy Conservation, Health & Environment

About:
Energy conservation, health & environmental KPIs should focus on the percentage of lubricants disposed of relative to lubricants purchased, the amount of lubricant contaminated waste, the use of spill containment materials, leak volume indicators, the cost of leaks, and the measure of education program compliance in ecological disposal of lubricants.



In the present market conditions, most facilities are trying to stretch lubricants as far as possible to avoid the hassle and cost of purchasing more. With supply chain disruptions, lack of raw materials and difficulty finding lubricant packaging, it is becoming more important than ever to ensure there isn't waste in the lubrication program related to the volume of lubricants used. The topic of waste is not a new one, especially when it comes to lubricants, but it seems to be one that is rarely tracked or monitored. In terms of disposal, lubricant purchases and a necessary check on our leakage protocols, few datasets can be more impactful.

Most organizations have an idea of what they spend each year out of their budget on lubricants, but few break it down to a specific volume of each lubricant that is purchased. Even fewer have an understanding of the total volume needed to fill every compartment in the plant. Therein lies one of the biggest opportunities to turn the Oil Consumption Ratio into an actionable target. The Oil Consumption Ratio is simply comparing the total volume of lubricant purchased to the total volume needed in the facility. This is a key performance indicator to help us monitor many aspects of the lubrication program but is often utilized as a metric to showcase how a program is maturing.

In its infancy, a lubrication program is often filled with unnecessary tasks such as over greasing, oil changes performed too often and leakage. As you can imagine, some of these are easier to fix than others, and some are more popular choices to attack than others. It's not simply a matter of deciding not to change oil as often or to grease once a month instead of once a week; a fair amount of homework has to be done to help mature the program to where we have optimized our lubrication cycles. Leakage is a more straightforward fix but, depending on the system complexity of duty cycles, leaks may be hard to pinpoint and fix. Regardless, we can walk through the process of how to implement this KPI:

First, we need to baseline where we are currently sitting in terms of purchasing. Getting with the procurement team, we should be able to see how much money was spent on lubricant purchases over the last several years. While the cost is great to know, we are really looking to discover the total volume of lubricant ordered. This may be tedious, but getting a volume for each lubricant is the first step of the process. Some companies may decide to focus on the total volume and not break it down to individual lubricants, but there are benefits to seeing the details. This will become clearer as we move through the process.

While it isn't necessary, determining how much of the lubricant exists in warehouse locations throughout the plant is what you should determine next. This would also be best broken down into each individual lubricant. When you start looking through all storage areas, you may be surprised by how many drums/buckets/totes of single lubricants you have sitting around. While the stored lubricant may feel like a stockpile for use when there are "emergencies," it is actually a liability. Too often, these stored lubricants are beyond their shelf life; they could be grossly contaminated to the point that they aren't fit for use. Also, a significant amount of stored lubricant may skew the consumption ratio, so understanding current inventory levels as well as maximum, minimum and reorder levels is important.

Oil Consumption Ratio Optimization

	Prior Year	Year 1	Year 2	Year 3
New Purchases	10,000 gal	4,500 gal	2,100 gal	1,420 gal
Machine Volume Charge	4,200 gal	4,600 gal*	4,600 gal*	4,600 gal*
Consumption Ratio	2.4	0.98	0.49	0.29

*New machines purchased

$$\text{Consumption Ratio} = \frac{\text{Annual Oil Purchases}}{\text{Machine Charge Volume}}$$

Once we have established our history of purchased volumes and our current stored volume, we need to figure out just how much of each lubricant is needed to completely fill all the machinery in the plant. While this task takes time and manpower, it yields powerful results. It is common for plants to know the details of large reservoirs or critical equipment; smaller pieces are often disregarded, and the information simply doesn't exist in the CMMS. This process allows us to put eyes on each piece of equipment, determine the volume, collect valuable operating data, and, ultimately, update our lubrication system (even if that is the CMMS). Keep in mind that, through this process, you should only focus on equipment that you intend to maintain. If you have a threshold of what is deemed "disposable," then use that as your guide. Any equipment that is sealed or simply ran to failure should be neglected from this audit. As you are collecting the volumes, this serves as a good spot check on your labeling of equipment for lubricants, as well as naming/numbering for consistency.

Finally, we want to check past work orders to determine how many of the pieces of equipment have recently had oil changes or significant top-ups. Perhaps many of you might not have that information available, which is okay, but it is something you will want to begin tracking and updating your work orders to include. This is also something that should be turned in with inspection routes/rounds. If an operator, lube tech or mechanic is topping something up, we want to know how much oil was added. This begins to let us determine where our biggest offenders are for our consumption ratio.

Once we have finished the data gathering and auditing stages, we are ready to begin developing our Oil Consumption Ratio dashboard. This can simply be a spreadsheet where we house the information. At the highest levels, we would place the total volume of lubricant purchased under the total volume of lubricant needed in the plant. A simple division of purchase volume by machine volume gives us the consumption ratio. Starting out, it is not uncommon to see a ratio of over two (purchasing more than twice the volume of lubricant needed to outfit the plant), but ideally, we should try to get as close to 0.2 as possible. To truly make the most out of this metric, you can break it down into more detail by showing the total volume of each specific lubricant purchased to the machine charge for that lubricant to find where the biggest offenders are and where areas of opportunity exist.

When you have the dashboard built, the focus shifts to automating data retrieval (to update the KPI). While this is often a yearly metric that is tracked, it can be updated monthly to show improvements on equipment classes that we are focusing on, such as hydraulics or gearboxes. This is where the work orders for oil changes and top-ups really help us understand where all the lubricant is going. For an even better look at consumption, you can compare purchase volume to disposed volume; this is an indicator of how well your lube disposal program may be running.

While this metric may sound like something that is simply "nice" to do, you need to realize that it is focused on more than just the amount of money we're spending on lubricants. When we stop to analyze the data, this metric can serve as a necessary check on many of our processes, including:

- **Leakage** — This is perhaps one of the biggest offenders to this metric. Not only does leakage require more lubricant, but it also cuts into our manpower. The hidden costs of leakage are no secret; there are disposal costs, spill cleanup costs and decreased equipment efficiency.
- **Failures** — One of the first things to happen when there is a significant equipment failure is the draining of oil. Once the repair is finished, the oil is refilled. This eats into the consumption ratio as many failures are avoidable and, with proper lubrication practices, shouldn't occur in the first place.
- **PM Optimization** — As mentioned previously, many activities are done within a timeframe that was established without any reasoning. This leads to relubrication occurring more often than needed, thus consuming more lubricant than needed. Focus on dialing in the relubrication frequency based upon the remaining useful life of the lubricant and analysis of the data collected during the equipment audit. You might be amazed to find that the machines you are greasing weekly or changing oil in yearly might be able to go two to five times longer between relubrication, even on a conservative scale.
- **Storage/Stock Rotation** — if the equipment isn't consuming the lubricant, then look at the storage areas. This may shine the light on products that are sitting static and not moving through the lube room as quickly as we once thought they were. Periodic walk-downs of these areas are great, but seeing in the ratio that lubricants are sitting in storage can be eye-opening to most program owners.
- **Inventory "Shrink"** — While it will be extremely difficult to account for every drop of lubricant coming into the plant, by comparing our usage to purchases to disposal volumes, we can start to uncover where our lubricant "shrink" may exist. This may be coming from leaks or spills that aren't recorded or top-ups that aren't turned in because our route sheets are "pencil whipped." If the oil is consumed and not disposed of, this gives a great clue that our problem may be internal leakage.

The Oil Consumption Ratio has much to ffer in terms of deliverable data. This KPI should be updated whenever new equipment is installed to keep it as accurate as possible. It also serves as a useful dataset to show how the lubrication program is maturing. We should try to minimize the consumption ratio year-over-year. This falls in line with many of the sustainability and environmental goals of companies. Plus, this provides us a great platform to showcase savings based upon hard dollars and not cost avoidance. Use the KPI to win over management and to get people on board with investments in the lubrication program. ***ML***

About the Author

Wes Cash is the Vice President of Services for Noria Corporation. He serves as a senior technical consultant for Lubrication Program Development projects and as a senior instructor for Noria's Oil Analysis I and Machinery Lubrication I and II training courses. He holds a Machinery Lubrication Engineer (MLE) Machine Lubrication Technician (MLT) Level II certification and a Machine Lubricant Analyst (MLA) Level III certification through the International Council for Machinery Lubrication (ICML). Contact Wes at wcash@noria.com.

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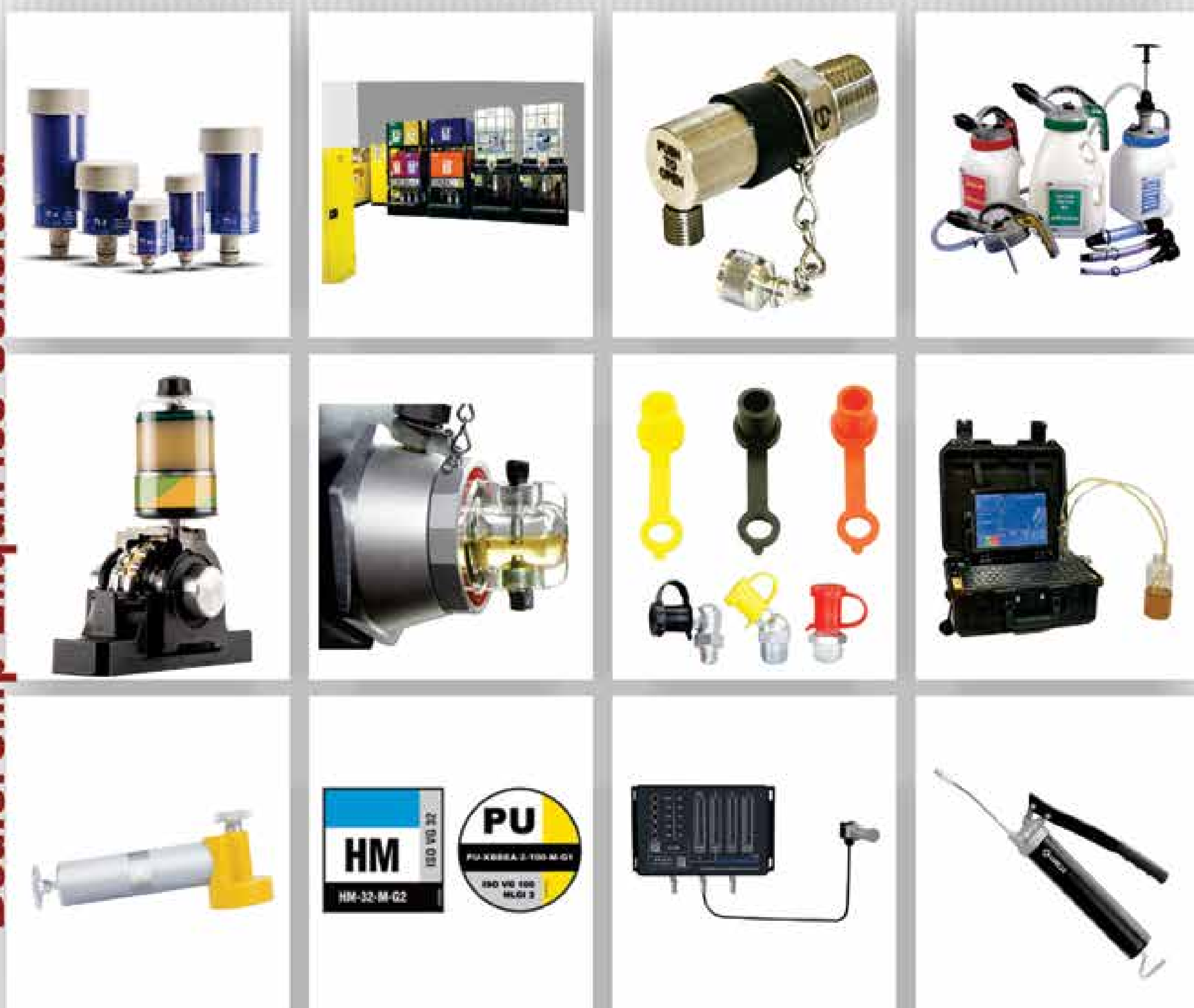

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