Particulate Contamination – Identifying, Eliminating and Removing it.

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In an ideal world, bearings would not fail until the theoretical bearing life (L_{10}) is obtained. Unfortunately, we do not live an ideal world and many premature bearing failures are attributed to particulate contamination. It is well known that keeping the oil clean will result in longer life of both the lubricant and equipment it is lubricating. In this session, we will cover where these particles come from, how to measure and quantify using the ISO Cleanliness Codes, and cost effective methods of removing it and even more importantly, eliminating it. It has been stated that the cost of excluding one gram of dirt is 10% of the cost to remove it once it enters the reservoir. Data on how one company successfully maintained cleanliness codes below the OEM recommendations by properly selecting and applying a Portable Filtration system will also be discussed.

Introduction

Contamination control is part of proactive maintenance, where the strategy is to minimize the ingression of particulate and other undesirables from the lubricant, to maximize lubricant and machinery life. Controlling contamination is a three step process that involves: First: Identifying the contaminant, Second: Eliminating the contaminant and Third: Excluding the contaminant. Identifying and eliminating the contaminant is important but excluding it will be the most cost effective in the long run.

Contamination is the primary cause of machine and lubricant failure and controlling it can be done effectively with out spending significant money. Typical classifications of contaminants are particulate, water, heat, air, glycol, soot, and fuel. The two most common contaminants are particulate and water and particulate will be the focus of this presentation. Analyzing fluid contamination is crucial for determining what the contaminants are, the potential source of the contaminants, and how they are affecting the oil's capability of performing its' primary function of controlling friction. Understanding the source of the contaminants allows corrective action and the development of a proactive maintenance program.

Adverse Affects

Particulate contamination affects both equipment and lubricant. Particles cause changes in viscosity which is the most important physical property of a lubricant. Proper selection of viscosity is required to support the load and prevent metal to metal contact. Particles also attack the base oil accelerating oxidation and attacking the additives rendering them ineffective.

The critical or dynamic clearance in most industrial equipment is less than 10 microns and human visibility is limited to 40-50 microns. The most damaging particles are smaller than what we can see. What happens in a rolling element bearing with clearances of 1 micron if a 1 micron particle is allowed to penetrate the load zone? The entire load is now supported by this particle and this reduction in contact area results in a stress level higher than the design, and eventually tiny cracks will form and propagate, which is called spalling of the bearings. Bearings can have an infinite life when particles larger than the lubricant film are removed. There are many factors that bring bearings to premature demise, but contamination of the lubricant can account for up to 70% of all bearing failures.

Particles cause various mechanism of wear, such as abrasive wear causing scratches and scars to metallic surface, erosive wear in systems where fluid is flowing, and fatigue wear where particles impede the critical load zones as discussed previously. These particles impede lubricant performance and further localize pressure on components causing denting, fatigue, spalling and abrasion to the surface of mating surfaces. The potential destructiveness of particles depends on their size, hardness, shape, density and the ability of these particles to enter the load zone.

Where do Particulates come from and how can they be excluded?

Sources of particulate contamination can be built in, internally generated, externally ingress, or maintenance induced. Factors to consider for determining where the particles come from and methods of excluding include:

- Cleanliness of new oil
- Proper storage and handling
- Ventilation and breathers
- Seals
- Service- During rebuild process
- Internally generated

Contamination is perceived to occur only during equipment maintenance and operation but can also be present in the oil prior to it being put into the equipment. It can not be assumed that new oil is clean and should be tested to establish a baseline for oil analysis but also to ensure that targeted contamination levels are obtainable. The storage, handling and dispensing of oil by the lubricant manufacture, distributor and in the plant are all areas where contamination ingression can occur causing particulate levels to be higher than targeted levels. Open to air transfer containers, storing lubricants outside, and drums left open are not considered best practice.

Majority of equipment needs to vent to prevent pressure build up that occurs when air within the sump heats up and cools down during start up and shut down. This breathing in and out is a primary source of contamination ingression and occurs through some type of vent on top, through the oil lubricator or through the seals. Equipment will typically come standard with some type of vent with a metallic filter element. Majority of these vents only prevent particles of 10 microns or higher from entering the sump whereas the most damaging particles are the 1-3 microns. An open "J" type **(Figure 1)** of vent does not have any type of filter and is mainly found on older equipment and is not a good venting practice. Good ventilation practices involve using a spin on type of filter, a desiccant breather or an expansion chamber **(Figure 1).** Which one is best to use depends on the equipment and environment. For example, a large exchange of air occurs during fluid level changes in a reservoir and an expansion chamber would not be sufficient, but a properly sized desiccant breather would be applicable.

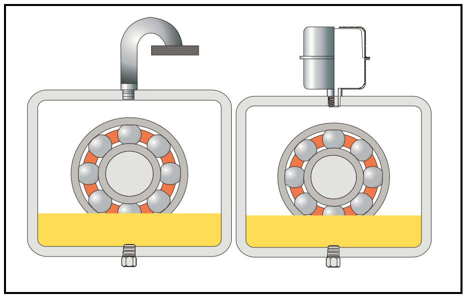

Figure 1 – Left Image – Poor Venting Practice – Open J tube, Right image – Good Venting Practice – Expansion Chamber

Constant level oilers also can be a source of contamination ingression dependent on the type. Constant level oilers require air to function and in vented oilers, this air is from the surrounding environment. As the equipment cools down, air is breathed in through the vents of the oiler, and any contaminants present will also be breathed in. In a non-vented type of oiler, the air supply is the same as the sump air eliminating ingression.

The primary purpose of a seal is to prevent lubricant leakage and contamination ingression. There are two types of seals – Contact and non-contact – Contact type of seals are Lip and Face seals, Magnetic. The lip seal is good at preventing contamination but being a contact type, eventual wear occurs allowing for contamination ingression. Magnetic seals have one rotating and one stationary face that are held together magnetically providing a hermetically sealed housing. Bearing Isolators are a non-contact type of seal and have one rotating and one stationary face and are very good at keeping contamination out and are the most popular type of seal found on new motors and pumps.   Some seals are not capable of handling the pressures due to equalization and would require an expansion chamber or proper breather.

The best way to prevent contamination from entering equipment is to close it up with the proper accessories that do no cause any pressure build-up. Non-vented oilers and reliable seals are recommended in highly contaminated environments and proper venting needs to be considered. An expansion chamber, desiccant type of breather, spin on filter element or plug should be used depending on type of seal and environment.

Contaminants are also generated during the assembly of components, break in of system and general operation. These contaminants can be identified as coming from components during the oil analysis process. Oil changes with proper flushing and cleaning of the housing will remove these components and filtration is another option when it is not economic to change the oil.

Quantifying Particulates – ISO Cleanliness Codes

Particulate contamination will always be present in rotating equipment and it is important to establish steps towards keeping this contamination to acceptable levels. First, determine what the acceptable cleanliness levels are and then take specific actions to achieve these levels such as reducing ingression, improving filtration or breather filtration. Frequent measuring is required to monitor the progress and determine what changes, if any, are required to hit the targeted levels. It is important that these measurements are consistently taken and reported. Once an improvement is seen, it will validate to everyone involved how their roles in the process contributed to hitting the goal.

Particle concentrations are reported using the ISO code **4406-99 (Table 1)** which reports the quantity of particles for specific sizes, 4, 6 and 14 microns respectively. This code establishes a relationship between particle counts and cleanliness of lubricants and allows a user to set targets based on quantifiable measurements. For example, a sample was pulled with results of:

- 1752 particles larger than 4 microns
- 517 particles larger than 6 microns
- 55 particles larger than 14 microns.

These particle concentration values are matched against the ISO chart and a specific number assigned. Particle concentration levels of 1752 larger than 4 microns falls between 1300 and 2500 and is cleanliness code of 18. Particle concentrations levels of 517 larger than 6 micron fall between 320 and 640 and is a cleanliness code of 16. Particle concentrations levels of 55 particles larger than 14 microns falls between 40 and 80 and is a cleanliness code of 13. The cleanliness of this oil is reported as an ISO 18/16/13. If the oil was filtered and the code was now 17/15/12 it would be up to twice as clean as the particle count range doubles for each increase in code level.

Particle Concentration (particles per milliliter)	Range Number
130,000 – 250,000	28
640,000 – 1,300,000	27
320,000 – 640,000	26
160,000 – 320,000	25
80,000 – 160,000	24
40,000 – 80,000	23
20,000 – 40,000	22
10,000 – 20,000	21
5,000 – 10,000	20
2,500 – 5,000	19
1,300 – 2,500	18

640 – 1,300	17
320 – 640	16
160 – 320	15
80 – 160	14
40 – 80	13
20 – 40	12
10 – 20	11
5 - 10	10
2.5 – 5	9
1.3 – 2.5	8
.64 – 1.3	7
.32 - .64	6
.16 - .32	5
.08 - .16	4
.04 - .08	3
.02 - .04	2
.01 - .02	1

Table 1: ISO 4406-99

Target cleanliness levels should be established for all lubricating and hydraulic oil using the Manufacturer levels as guidelines and not the ultimate goal. Manufacturers will give guidelines only, and are not familiar with the specific environment that the equipment is in and specifically the level of contamination present. Consider the design of the equipment and application and set life extension targets for each, such as one cleanliness code cleaner. Setting too aggressive of levels from the start is not recommended as it can create frustrations when goals are not met and possible abandonment of goal. Typical base cleanliness targets are summarized in **Table 2.**

Machine/Element	Target ISO Code
Roller Bearing	16/14/12
Journal Bearing	17/15/12
Industrial Gearbox	17/15/12
Steam Turbine	18/15/12

Table 2. Typical Base Target Cleanliness Levels

The third step is to monitor particle count concentrations to establish a baseline and periodic measurements will determine the success of the actions taken to reduce the concentration. Depending on where the sample is pulled will determine the benefits of particle counting. Some of the key benefits of particle counting include: monitoring the machine break in, identifying abnormal wear, determining when portable filtration is required, identifies how efficient the filters are, and can aid in troubleshooting and isolating problems. As mentioned previously, it is very important that these results are reported to all personnel involved in the corrective actions to promote awareness.

Removal Methods

Factors to consider for removal of contamination include:

- Proper clearance filters
- Off-line filters for some machines
- Portable filter for other machines
- Proper sump and reservoir management
- Timely filter servicing

Filtration is the most common method used for removal of particulates. A filtration system can either be stationary or portable depending on equipment design, criticality, target levels established, and environment. A portable filter cart is used to both clean existing oil as well as transfer fluid from storage containers to equipment to ensure only clean oil is being put into equipment.

Determining where filtration should occur in a system depends on criticality of each component as the cost of filtering can vary significantly. The graphic below (**Figure 2)** represents a reservoir of oil that is circulated to a specific piece of equipment. A strainer on the suction inlet is important to prevent the larger particles from entering the system, but it not effective at limiting the smaller particles that can do the most damage. An off line filtration system provides the lowest cost per gram of dirt removed assuming an adequate flow rate is available. A pressure line filter on a Hydraulic system is very effective, but costly due to the selection of filters with the correct pressure and flow ratings. The return line filter is an ideal location for hydraulic systems as you can increase size and efficiency for cyclic flow conditions.

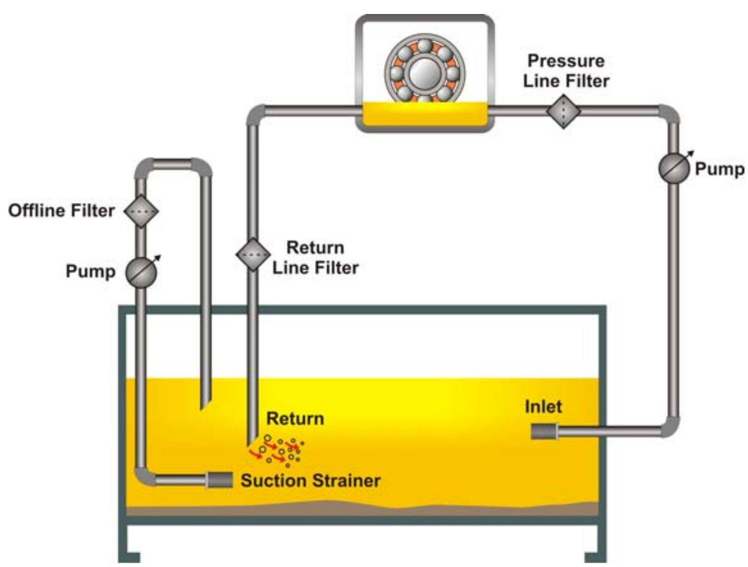

Figure 2: Filter Location Options

Case Study – Applying Portable Filtration System

A major paper company in the south has a gearbox application where oil analysis consistently reported high particle concentrations. The gearbox holds approximately 100 gallons of EP ISO 220 weight oil and it is not possible to continually change the oil as it requires the plant to shutdown. For years, the end user tried various Hydraulic Filter carts as well as homemade versions to clean the oil, but with limited success. Filtering higher viscosity fluids effectively requires the selection of the proper motor and pump as well as filters to handle the more viscous fluid. A standard Hydraulic Filter cart would typically run in bypass mode due to the increased pressures. The customer purchased a cart specifically designed to handle higher viscosity fluids and conducted some testing. A sample of oil was pulled and the cleanliness level was found to be 21/18/14 which is quite a bit dirtier than the recommended levels (17/15/12) for a gearbox application. The gear oil filter cart was connected to the reservoir of the gearbox and the oil was filtered for 48 hours while the equipment continued to run. A sample was pulled after the 48 hours and the cleanliness code dropped to 17/15/13, very close to the desired levels. Another sample was pulled after 72 hours and the cleanliness code dropped to 15/14/10.

The number of microns per milliliter in 72 hours went from:

- 10,000-20,000 ≥ 4 microns to 160-320 ≥ 4 microns
- 1,300-2,500 ≥ 6 microns to 80-160 ≥ 6 microns
- 80-160 ≥ 14 microns to 5-10 ≥ 14 microns

By selecting the correct filtration product for the application, this end user was able to achieve cleanliness codes below the manufacturer's level. There are many financial benefits to keeping the oil clean.

Summary

Minimizing contamination related failures of both the lubricant and equipment can be accomplished by first identifying the contaminant, removing the contaminant, and most importantly, excluding the contaminant. Understanding the source of contaminants needs to start with when the oil is received and followed all the way through to each specific piece of equipment. Surrounding environment needs to be considered as well as the design of equipment to ensure ingression is limited. Measurement of contamination with frequent Oil Analysis is required and proper selection of Filtration products to maintain acceptable levels. Continuous improvements in excluding contaminants and applying proper removal methods will help achieve the targeted goals for continual success in your lubrication program.