Separating the Competition

Centrfuge vs. Turbo-TOC™
Case Study

EXTENDING YOUR ENERGY

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KAYDON FILTRATION

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Centrifuge verses TURBO-TOC

Turbines require extremely clean and dry oil.

When 100 tons of turbine components are spinning at 3600 rpm, the need for clean dry lubricating oil is absolutely required for long-term reliability. Turbine lube oil can be processed using several different purification systems. Kaydon Filtration is a manufacturer of purifiers that use coalescing and micronic filtration to remove water and particulate debris from the lubricating oil. We are often asked why our Turbo-TOC® is a better method to remove water and dirt than centrifuging the oil.

Major reasons why the Kaydon Filtration TURBO-TOC is better:

1. Removes the most damaging wear particles
2. Removes water in emulsion
3. Less costly initial price
4. Less costly to operate
5. Better oil quality

Modern turbines use sleeve bearings, to support the turbine and reduce rotating friction. These families of bearings are often called sliding bearings or journal bearings. While these bearings appear to be rather simple, a significant amount of complex theory has entered into the bearing design and the requirements of the oil lubricant.

Kaydon Filtration, as a supplier of turbine oil filtration to this industry for the past 60 years, has devoted a significant amount of study to the critical operating parameters for maintaining bearing oil reliability. As journal bearings begin to rotate, oil is pumped into the oil grooves of the bearing housing. As speeds increase, a hydrodynamic film develops to separate the shaft or journal from the bearing surface. There is significant data about film thickness, clearances between bearing surfaces and journals; however, the question of filtration type and efficiency is left to the operator.

Journal or sleeve bearing is used in turbines

The choice of filtration system is often selected by past experience and cost, rather than the best technical and long-term economic solution. This paper examines the best method based on the fluid cleanliness requirements.

This article examines the issues of fluid cleanliness as it applies to both maximum particle size and water concentration required by a journal bearing. After this examination, a comparison will be argued between the level of cleanliness obtainable from a centrifuge and coalescing system.

Oil Film Thickness

In a sliding bearing, the rotating member or journal is supported by the bearing. A typical journal bearing is pictured to the left. The bearing portion is often referred to as the sleeve. The sleeve portion is lined with a soft metal like brass, bronze or babbitt. The shaft or journal rides on an oil film within the sleeve. The lubricating oil is pumped through holes into the bearing area to support the shaft from riding directly on the liner material. The soft sleeve lining is more malleable and acts as a cushion between the shaft and in some cases the wear particles trapped in the film gap. The manufactured clearances between sleeve and journal are in the order of approximately 25 to 50 microns for every 1" of shaft diameter. The journal doesn't center itself between the sleeve. It rotates at the lowest point and depends on the pumped oil flow to create a film thickness.

This film thickness varies as a function of shaft diameter and rotational speed. At start-up the metal is in direct contact with the bearing material. As speed increases, the oil is pulled into the gap and the clearance increases. So the most damage is done at start-up, when the particles of contamination are greater than the film thickness. The film thickness has been calculated by mathematical models and empirically examined. The film thickness can vary from about 1 micron to 10 microns for bearings in the 2 to 8" size.

Particles that create the most damage

The majority of wear is abrasive wear, caused by oil carrying the grit causing the abrasion. The softer babbitt can allow some of these particles to imbed in the surface. The solution is to remove the damaging particles. The most damaging particle size is the one equal to or greater than the film gap. For typical journal bearing in the 2 to 8" diameter, the film thickness is around 1 to 10 microns. Under start-up and lower RPM conditions it expected that the film thickness, and thus the particle size to be removed, is around 5 microns.

Filter Size and Efficiency of Centrifuge

If we need to remove particles 10 micron or greater at a 100% efficiency, then filtration must be accomplished by the centrifuge or filter/coalescer. The centrifuge relies on spinning the particles at high enough velocity to separate them from the oil supply. The performance of a centrifuge can be calculated mathematically. The following formula applies:

$$D_{min} = 553[\ SpG * Vo * Q/ \{r * h * \{SpGc\text{-}SpG\}* N\}]^{\frac{1}{2}}$$

Where:

Dmin	= minimum radius of particle to be removed in microns
SpG	= Specific gravity of the fluid be purified, typically oil
SpGc	= Specific gravity of the contaminate
Vo	= kinematic oil viscosity at operating temperature (ft^2/sec)
Q	= System flow rate in GPH (US Gallons per hour)
r	= radius of the entry holes' centerline relative to the center of rotation of the discs
h	= Total height of the discs within the centrifuge
N	= g rating of the centrifuge typically about 2200

If we take a typical application where the oil viscosity is 100 SSU (.00021 ft^2/sec), flow rate through the centrifuge is 600 gph, r =.5ft, h =.583, and the gravitational force is N = 2200 then:
Maximum particle size of a silica or dirt particle (1.2 specific gravity) removed from oil using the same variables listed in the sample above is approximately 13.6 microns. Iron and copper are the high density wear compounds. A centrifuge will remove these down to about 2 ½ to 3 microns.

The chart shows the theoretical particle removal efficiency of a centrifuge based on various specific gravity compounds when the gravitational force is 2200 g's. Notice that the debris, which initiates the abrasion process, is typically dirt or sand-like compounds. These compounds have a specific gravity around 1.2. Particles less than 13 microns will not be removed.

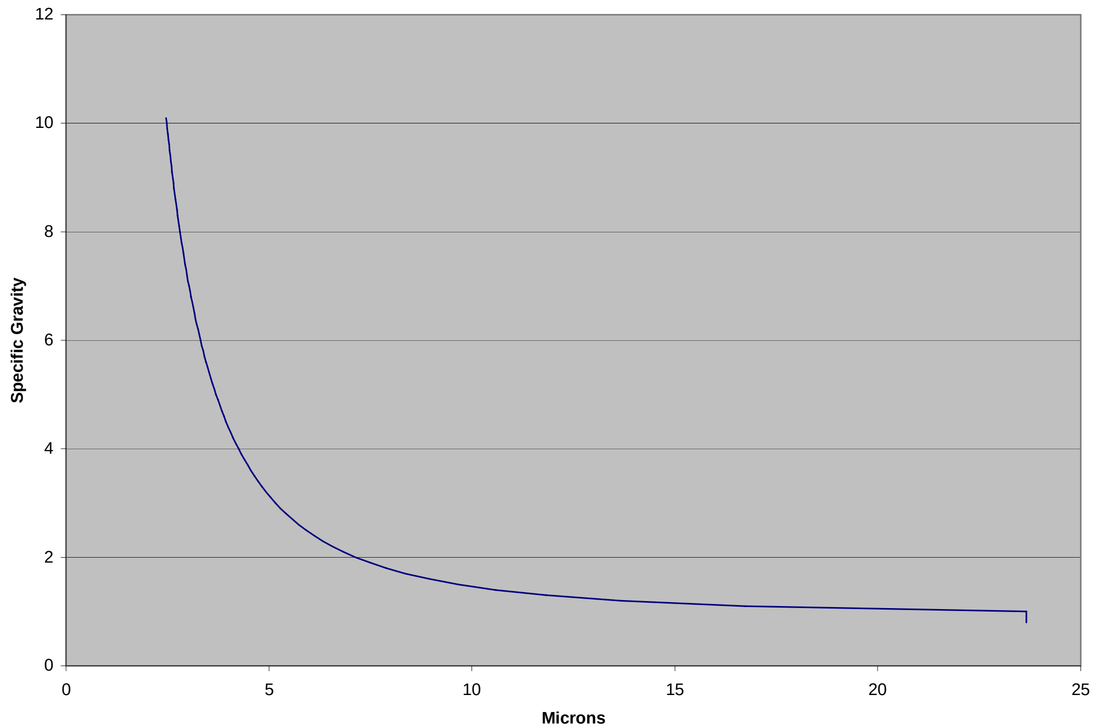


Figure 1

The chart shows the theoretical particle removal efficiency of a centrifuge based on various specific gravity compounds when the gravitational force is 2200 g's.

Filter Size and Efficiency of the TURBO-TOC

Unlike a centrifuge, a cartridge filter has no limitation based on gravities or viscosities. ISO standard 16889 evaluates an oil filter to determine the pore size. Also, particulate removal efficiency (Beta Ratios) can be calculated from this test. A Beta Ratio is the ratio of the number of particles entering the filter divided by the particles exiting the filter. For example, if a test shows 7500 particles 4 microns and larger entering the filter, and the downstream count is 100 of the 4-micron size and larger, the Beta (ß) ratio is 75 (7500 divided by 100). The same filter, when challenged with 10-micron particles, will show a higher Beta rating (approximately 1000).

Beta Ratio	Efficiency
2	50%
10	90%
75	98.7%
200	99.5%
1000	99.9%
10000	99.99%

Eff = Beta Ratio-1/Beta Ratio or Beta Ratio = -1/(Eff-1)

The benefit of using a 4 micron high efficiency filter allows for the removal of very fine sand and debris that causes major wear at the low speeds or smaller bearing diameters. Under normal operating situations the 10-micron particles are virtually eliminated. In addition the fine particles are removed for higher quality oil purity at start-up or shut down when the clearance between journal and sleeve is reduced.

Water Removal
Water is more destructive to a bearing than particulate matter. Water still remains the primary contaminant that leads to short life on a turbine bearing.

Traditional thinking has always taught that water separates immediately from oil. Also, remember the old saying, “water and oil don’t mix”? Well it does mix, and forms emulsions. Water can also dissolve into oil just like water dissolves into air. This level of water saturation in air is known as relative humidity. Oil can dissolve water into itself as the temperature increases, as the oil ages, and as the viscosity increases.

Figure 2 Dissolved, emulsified and free water in oil, with a biological contamination at the water interface.

The amount of water dissolved in turbine oil can be between 100-250 ppm under normal operating conditions. When the oil is saturated to its maximum, a decrease in temperature can cause the dissolve water to precipitate out and form either free water or an emulsion with the oil. The droplet size is below 1 micron to perhaps as much as 2 micron in diameter. The addition of additives and the very small droplet size prevents the water from separating naturally by gravity.

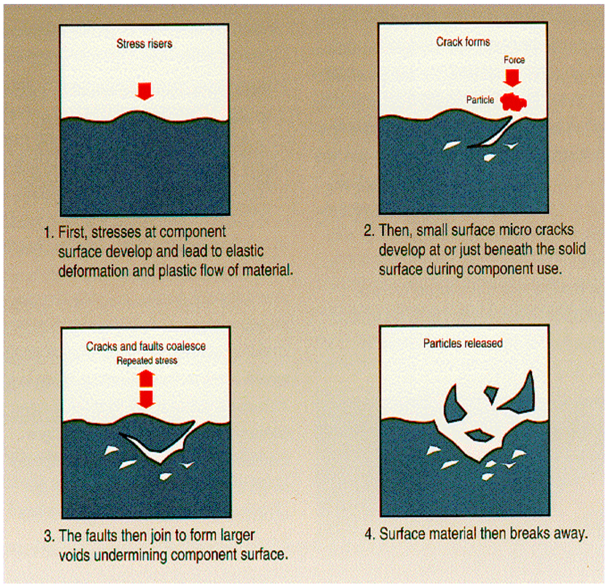
Continuing to have water ingress into a lubrication system can increase the amount of emulsified water. Continued agitation and passage through oil feed pumps continue to emulsify the oil. A water removal filtration system is the best defense against water build-up.

Effects of Water on Bearings and Lubricants
Not only does the water play havoc on the metal components of a journal or roller bearing, it also reacts chemically with the lubricant. Water can oxidize the oil at such a rate that the anti-oxidant additives are pre-maturely expelled. Oil oxidation can be increased as much as 10 times in the presence of elemental iron and copper. Water will also react with Anti-Wear (AW) and Extreme Pressure (EP) additives. While not common in turbine oils, AW and EP reaction products are acidic. They can cause corrosive wear in metals, such as Babbitt.

Bearing failure from excess water

As the concentration of water increases in an oil system, the load on a journal bearing can overcome the hydrodynamic oil film causing metal-to-metal wear. High load pressure in any bearing can cause flash to steam in the load zone. The flash to vapor can cause erosive wear on bearing surfaces.

The most catastrophic failure is a water-accelerated fatigue wear. Under load, bearing surfaces in the Babbitt can form very small cracks. These micro cracks can be filled with water and under the high pressure of the journal, the water can be separated into oxygen and hydrogen. The hydrogen reacts with the bearing surface and creates a weak compound at the crystal interfaces. The term is hydrogen embrittlement. The fatigue crack will eventually spread to the surface on all sides and create a spalling or surface pit. The surface damage may have happened normally, but the water accelerates the process and is one of the prime reasons for short bearing life.



Fatigue wear results induced by pressure and accelerated by water in oil.

If machinery failure is to be avoided, moisture and particulate matter must be removed from the lubricating and hydraulic oils.

In JW MacDonald's article *"Marine Turbine Oil System Maintenance",* catastrophic failure can be attributed to free water build up. Appledoorn, Goldman and Tao in *"Corrosive Water by Atmospheric Oxygen and Moisture"* supported these findings and added that the effect of aeration with water was significant. Wilson in two articles *"Problems Encountered in Turbine Lubricants and Associated Systems" and "Corrosion of Tin Base Babbitt Bearing in Marine Steam Turbines"* described the effect of water on babbitt type bearings. Cantley in "The *Effect of Water in Lubricating Oil on Bearing Fatigue Life"* predicted bearing life based on concentration in oil. Schatzberg and Felsen *in "Effect of Water and Oxygen During Rolling Contact Lubrication"* pointed out that dissolved water in concentrations .01 % (100 ppm) can cause hydrogen embrittlement and corrosion leading to subsequent bearing failure. These and others all support findings that water in free, emulsified, or dissolved form are extremely detrimental to bearings.

Our target is to get the free and emulsified water from the oil. The water droplet size is typically in the range of 1-5 microns in diameter when emulsified with the oil. If we re-examine our equation for predicting centrifuge performance:

$$D_{min} = 553[SpG * Vo * Q/ \{r * h * \{SpGc-SpG\}* N\}]^{½}$$

Using the same sample data as before, we find the minimum water droplet size is approximately 23 to 24 microns. Significantly higher than the droplets found in emulsified oil water systems. A centrifuge can remove gross free water from leaking covers, wash down situations and the like, but dryness levels 100 PPM are accomplished only with a Turbo-TOC® coalescing system.

The Turbo-TOC® has no limitations to the droplet size. Coalescing is accomplished by the impingement of the water on the micro-fibers of the coalescing media. As the amount to water increases, the droplets merge and coalesce into large droplets. The hydraulic pressure of oil flowing through the cartridge expels these droplets. The droplets are on the order of 1/8" to 3/8" in diameter and settle rapidly to the sump area of the Turbo-TOC® coalescing vessel. Dryness levels of 100-ppm residual water are common performance capabilities for the Turbo-TOC®.

	Recommended Practice	TURBO-TOC
Maximum Particle Size (microns)	5-8	4
ISO Cleanliness Code	18/16/13	16/14/11
Free and Emulsified Water (ppm)	25	0
Total Water (ppm)	250	100

Operating Issues

There are significant operating issues of a centrifuge compared to a Turbo-TOC® coalescing system. The typical operating issues found with a centrifuge are:

1. The bowl is the rotating vessel where separated solids collect. These bowls must be cleaned regularly to maintain the performance of the centrifuge.
2. The shear pin is connected to the input shaft, which protects the gearbox from damage in overload situations. It is designed to break at a specific torque level without damaging the gearbox. When the oil is cold, the centrifuge "shear pins" have a tendency to break. Repeated breakage of the shear pin will eventually damage the gearbox.
3. Difficulty in finding parts for older centrifuges.
4. Centrifuges are difficult systems to operate and understand. Normally, a plant will have a long-term expert that understands the system and can provide the necessary maintenance and adjustments. When this "expert" retires, a plant is left without much operational knowledge of the system.

Summary of Performance

Many times the choice of using a centrifuge was based on past experience rather than comparing the performance of these devices. As noted, there are significant advantages to using a Turbo-TOC®. This table lists costs associated with operating either unit. The comparison is made for a 10-gpm system.

TURBO-TOC Filter/Coalescer	**Centrifuge**
Elements Change out: 2 sets of pre-filters, 1 set of coalescers & separators $ 720/year	Elements Change out: None
Operating and Maint. Labor 5 minutes per day @ $25.00/hour $760.00/year	Operating and Maint. Labor 2 hr/week to clean and remove particulate @$25/hr 40 hrs/year to service Centrifuge $3600.00/year
Utilities 1.5 HP=1.12kw Heater is 15 kw but runs 10%=1.5 kw 2.62kw * 365 days *24hours = 22951kw-hrs $1606/yr at $.07 per kw-hr	Utilities 10 HP=7.46Kw Heater at 30kw runs 75%=22.5 30kw * 365days * 24hours=262,450kw-hr $18,371/yr at $.07 kw-hr
Approximate Total Annual Cost $3,086	**Approximate Total Annual Cost $21,971**

From this discussion, it is clear that today's need for reliable production of electric power, turbines require world-class lubricants and filtration systems. The centrifuge, gravity filters, and filter presses, were the steps in providing this reliability. Today the technical merits and lower operating costs of using the Kaydon Filtration Turbo-TOC® place the Turbo-TOC® system at the top of the list for maintaining turbine lubricants.