OIL and your engine

Foreword

Bearing failure, piston ring sticking, and excessive oil consumption are classic symptoms of oil-related engine failure. How do you avoid them? There are numerous ways, three of the most important being Scheduled Oil Sampling (S·O·S SM), regular maintenance of the lubrication system, and the use of correct lubricants. Following these recommendations can mean the difference between experiencing repeated oil related engine failure and benefiting from a productive and satisfactory engine life. This booklet attempts to tell the story of oil: what it is composed of and what its functions are, how to identify its contamination and degradation, typical consequences, and some preventive measures to help you protect your engine against the devastating effects of oil related engine failure.

Understanding Oil

Function
Engine oil performs several basic functions in order to provide adequate lubrication. It works to keep the engine clean and free from rust and corrosion. It acts as a coolant and sealant; and it provides an oil film cushion that keeps metal-to- metal contact to a minimum, thereby reducing friction and wear. But these are only the basic functions of oil. It is the particular demands of a given application and the special conditions under which an oil is used that largely determine the numerous additional functions oil must perform. These additional functions make choosing the correct oil for the job vital.

The selection of a suitable lubricating oil should be based on the engine performance requirements as specified by the manufacturer, as well as the application and the quality of the available fuel. Diesel engines, for instance, normally operate at lower speeds but higher temperatures than gasoline engines, making conditions exceptionally conducive to oil oxidation, deposit formation and corrosion of bearing metals. Under these conditions, the oil is expected to function in an expanded capacity. This is where additives are noticed. The final performance characteristics of the oil depend on the base oil and the additives used. The amount or types of additives used vary according to the properties of the base oil and the environment in which the oil will function.

Base Stocks
Lubricating oil begins with base oil or base stock. Base stocks are mineral (petroleum) or synthetic origin, although vegetable stocks may be used for specialized applications. The base stock provides the basic lubricating requirements of an engine. However, unless it is supported with additives, base oil will degrade and deteriorate very rapidly in some operating conditions. Depending on the type of base stock, petroleum, synthetic or others, different additive chemistries are used.

Mineral Oils Mineral stocks are refined from petroleum crude oils. The crude oil source and the refining process will determine the base stock characteristics. The crude oils used for diesel engine lubricants are primarily made up of paraffin, napthene, and aromatic compounds. The crude oils with higher paraffin content are most frequently used in blended engine oils.

The refining process begins with vacuum distillation. Vacuum distillation separates the oil into products with a similar boiling range and similar viscosities. After vacuum distillation, the oils must be purified to remove or modify undesirable compounds. Base oil purification is usually done by solvent extraction and hydrofinishing or by hydrocracking and hydrofinishing. Both of these processes are used to limit or eliminate wax, sulfur, and aromatics. Variations in these refining process produce base oils with different characteristics.

Mineral base stocks are most prevalent for diesel engine oil formulation because they exhibit proven characteristics and are readily available at a reasonable cost.

Synthetic Oils Synthetic base stocks are formed by processes that chemically react materials of a specific chemical composition to produce a compound with planned and predictable properties. These base stocks have viscosity indexes much higher than HVI mineral base stocks, while their pour points are considerably lower. These characteristics make them valuable blending components when compounding oils for extreme service at both high and low temperatures. The main disadvantage of synthetics is the significantly higher price and the somewhat limited supply. The group of synthetic oils known as esters causes greater seal swelling than mineral oils. The possible use of ester synthetic oils requires that component design be carefully considered for seal and ester oil compatibility. The use of synthetic base stocks lubricants in Caterpillar engines and machines is acceptable if the oil formulation meets the specified viscosity and Caterpillar performance requirements for the compartment in which it will be used. For very cold ambient conditions, the use of synthetic base stock oils is necessary.

Additives

Additives strengthen or modify certain characteristics of the base oil. Ultimately, they enable the oil to meet requirements beyond the abilities of the base oil.

The most common additives are detergents, oxidation inhibitors, dispersants, alkalinity agents, anti-wear agents, pour-point depressants and viscosity index improvers.

Here is a brief description of what each additive does and how.

Detergents help keep the engine clean by chemically reacting with oxidation products to stop the formation and deposit of insoluble compounds. The detergents in use today are metallic salts called: sulfonates, phenates, phosphonates or salicylates.

Alkalinity agents help neutralize acids. The detergents are also strong acid neutralizers, changing combustion and oxidation acids into harmless neutralized salts.

Oxidation inhibitors help prevent increases in viscosity, the development of organic acids and the formation of carbonaceous matter. These anti-oxidants are the following chemicals: zinc dithiophosphates, phenate sulfides, aromatic amines, sulfurized esters, and hindered phenols.

Depressants help prevent sludge formation by dispersing contaminants and keeping them in suspension. Common dispersant types include polyisobutenyl succinimides and polyisobutenyl succinic esters.

Anti-wear agents reduce friction by forming a film on metal surfaces and by protecting metal surfaces from corrosion. The principal types of agents are alkaline detergents, zinc dithiophosphates and dithiocarbamates.

Pour-point depressants keep the oil fluid at low temperatures by preventing the growth and agglomeration of wax crystals. Pour point depressant types are polymethacrylates; styrene- based polyesters, crosslinked alkyl phenols and alkyl naphthalenes.

Viscosity Index improvers help prevent the oil from becoming too thin at high temperatures. Viscosity index improvers (VI improver) are chemicals which "improve" (reduce) the rate of viscosity change with temperature change. Chemicals used as VI improvers are polyisobutenes, polymethacrylates, styrene-based polyesters, styrene-based copolymers and ethylene propylene copolymers.

Total Base Number (TBN)

Understanding TBN requires some knowledge of fuel sulfur content. Most diesel fuel contains some amount of sulfur. How much depends on the amount of sulfur in the crude oil from which it was produced and/or the refiner's ability to remove it. One of the functions of lubricating oil is to neutralize sulfur by-products, namely sulfurous and su.lfuric acids and thus retard corrosive damage to the engine. Additives (primarily detergents) in the oil contain alkaline compounds which are formulated to neutralize these acids. The measure of this reserve alkalinity in an oil is known as its TBN. Generally, the higher the TBN value, the more reserve alkalinity or acid- neutralizing capacity the oil contains.

Ash or Sulfated Ash
The ash content of an oil is the noncombustible residue of a lubricating oil. Lubricating oil detergent additives contain metallic derivatives, such as barium, calcium, and magnesium compounds that are common sources of ash. These metallo-organic compounds in the oils provide the TBN for oil alkalinity. Excessive ash content will cause ash deposits which can impair engine efficiency and power.

Viscosity
Viscosity is one of the more critical properties of oil. It refers to its resistance to flow. Viscosity is directly related to how well an oil will lubricate by forming a film to separate surfaces that would contact one another. Regardless of the ambient temperature or engine temperature, an oil must flow sufficiently to ensure an adequate supply to all moving parts.

The more viscous (thicker) an oil is, the thicker the oil film it will provide. The thicker the oil film, the more resistant it will be to being wiped or rubbed from lubricated surfaces. Conversely, oil that is too thick will have excessive resistance to flow at low temperatures and so may not flow quickly enough to those parts requiring lubrication. It is therefore vital that the oil has the correct viscosity at both the highest and the lowest temperatures at which the engine is expected to operate.

Oils change viscosity with temperature, becoming less viscous as their temperatures increase. Refining techniques and special additives increase the Viscosity Index (VI) of oil. The higher the VI number of the oil, the lower its tendency to change viscosity with temperature.

The Society of Automotive Engineers (SAE) standard oil classification system (SAE J300) categorizes oils according to their viscosity (via a number system such as SAE 10W, SAE 30, SAE 15W40, etc.).

Each of the viscosity grades or numbers has limits on the viscosity of the oil at given temperatures. For viscosity grades specified with a "W" the oil viscosity is defined by both viscosity at 100°C and at maximum low temperature for cranking and pumping. In other words, the oil's viscosity has been tested to verify the oil's flow under specified low temperatures. Therefore the "W" in an oil viscosity grade is commonly understood to mean that the oil is suitable for winter service. For grades without the W, the oil viscosity is defined at 100°C. only. The attached chart indicates the viscosities for the various oil viscosity grades.

SAE Viscosity Grades for Engine Oils[a] — SAE J300 Dec 99

SAE Viscosity Grade	Low Temperature Viscosities		High-Temperature Viscosities		
	Cranking[b] (cP) max at temp °C	Pumping[c] (cP) max with no yield stress at temp °C	Low Shear Rate Kinematic[d] (cSt) at 100°C		High Shear[e] Rate (cP) at 150°C min
			min	max.	
0W	6200 at -35	60,000 at -40	3.8	—	—
5W	6600 at -30	60,000 at -35	3.8	—	—
10W	7000 at -25	60,000 at -30	4.1	—	—
15W	7000 at -20	60,000 at -25	5.6	—	—
20W	9500 at -15	60,000 at -20	5.6	—	—
25W	13,000 at -10	60,000 at -15	9.3	—	—
20	—	—	5.6	<9.3	2.6
30	—	—	9.3	<12.5	2.9
40	—	—	12.5	<16.3	2.9 (0W-40, 5W-40, 10W-40 grades)
40	—	—	12.5	<16.3	3.7 (15W-40, 20W-40, 25W-40, 40 grades)
50	—	—	16.3	<21.9	3.7
60	—	—	21.9	<26.1	3.7

Note:

1 cP = 1mPa s: 1 cSt = 1mm2/s

[a] All values are critical specifications as defined by ASTM D 3244 (see J300 text)
[b] ASTM D 5293
[c] ASTM D 4684: The presence of any yield stress detectable by this method constitutes a failure regardless of viscosity.
[d] ASTM D 445
[e] ASTM D 4683, ASTM D 4741, CEC-L-36-A-90
The new standard carries a revision date of December 1999. Mandatory compliance with the new Cranking limits began June 2001.

API Engine Oil Classifications
The gasoline and diesel engine oil performance classifications are defined by the American Petroleum Institute (API) service classifications established jointly by API, SAE and ASTM (American Society of Testing Materials).

API gasoline engine oil classifications have two letter designations that start with the letter "S." The current active designations are API SJ, and API SL.

API diesel engine oil classifications have two letter designations that start with the letter "C." The current active four-stroke cycle diesel engine oil classification designations are API CF, API CF-4, API CG-4, and API CH-4.

API CH-4 oils were developed in order to meet the requirements of the new high performance diesel engines. Also, the oil was designed to meet the requirements of the low emissions diesel engines. API CH-4 oils are also acceptable for use in older diesel engines and in diesel engines that use high sulfur diesel fuel. API CH-4 oils may be used in Caterpillar engines that use API CG-4 and API CF-4 oils. API CH-4 oils will generally exceed the performance of API CG-4 oils in the following criteria: deposits on pistons, control of oil consumption, wear of piston rings, valve train wear, viscosity control, and corrosion.

Three new engine tests were developed for the API CH-4 oil. The first test specifically evaluates deposits on pistons for engines with the two-piece steel piston. This test (piston deposit) also measures the control of oil consumption. A second test is conducted with moderate oil soot. The second test measures the following criteria: wear of piston rings, wear of cylinder liners, and resistance to corrosion. A third new test measures the following characteristics with high levels of soot in the oil: wear of the valve train, resistance of the oil in plugging the oil filter, and control of sludge.

In addition to the new tests, API CH-4 oils have tougher limits for viscosity control in applications that generate high soot. The oils also have improved oxidation resistance. API CH-4 oils must pass an additional test (piston deposit) for engines that use aluminum pistons (single piece). Oil performance is also established for engines that operate in areas with high sulfur diesel fuel.

All of these improvements allow the API CH-4 oil to achieve optimal oil change intervals. API CH-4 oils are recommended for use in extended oil change intervals. API CH-4 oils are recommended for conditions that demand a premium oil. Your Caterpillar dealer has specific guidelines for optimizing oil change intervals.

API CG-4 oils were developed primarily for diesel engines that use a 0.05 percent level of fuel sulfur. However, API CG-4 oils can be used with higher sulfur fuels. The TBN of the new oil determines the maximum fuel sulfur level. See Illustrations 1 and 2 on pages 31 and 32.

API CG-4 oils are the first oils that are required to pass industry standard tests for foam control and viscosity shear loss. API CG-4 oils must also pass tests that were developed for corrosion, wear and oxidation.

API CF-4 oils service a wide variety of modern diesel engines. API CF-4 oils provide more stable oil control and reduced piston deposits in comparison to API CF and the obsolete CE and CD classifications of oil. API CF-4 oils provide improved soot dispersancy in comparison to API CF and obsolete CD oils. The API CF-4 classification was developed with a 0.40 percent sulfur diesel fuel. This represents the type of diesel fuels that are commonly available worldwide.

NOTE: Do not use single grade API CF oils or multigrade API CF oils in Caterpillar Direct Injection (Dl) Diesel Engines (except Caterpillar 3600 Series Diesel engines).

NOTICE: API CF is not the same classification as API CF-4. API CF oils are only recommended for Caterpillar 3600 Series Diesel Engines and Caterpillar engines with precombustion chamber (PC) fuel systems.

Some commercial oils that meet the API classifications may require reduced oil change intervals. To determine the oil change interval, closely monitor the condition of the oil and perform a wear metal analysis. Caterpillar's S·O·S Oil Analysis Program is the preferred method.

NOTICE: Failure to follow these oil recommendations can cause shortened engine service life due to deposits and/or excessive wear.

Diesel Engine Oil Recommendations

Caterpillar Diesel Engine Oil

Caterpillar Oils have been developed and tested to provide the full performance and service life that has been designed and built into Caterpillar Engines. Caterpillar Oils are currently used to fill diesel engines at the factory. These oils are offered by Caterpillar dealers for continued use when the engine oil is changed. Consult your Caterpillar dealer for more information on oils.

Due to significant variations in the quality and performance of commercially available oils, Caterpillar recommends:

- Caterpillar Diesel Engine Oil (10W30)
- Caterpillar Diesel Engine Oil (15W40)

Caterpillar multigrade Diesel Engine Oil is formulated with the correct amounts of detergents, dispersants, and alkalinity to provide superior performance in Caterpillar Diesel Engines.

Caterpillar multigrade Diesel Engine Oil is available in 2 viscosity grades: 10W30 and 15W40. For direct injection engines, see Table 1 to choose the correct viscosity grade for the ambient temperature. Multigrade oils provide the correct viscosity for abroad range of operating temperatures.

Multigrade oils are effective in maintaining low oil consumption and low levels of piston deposits.

Caterpillar multigrade Diesel Engine Oil can be used in other diesel engines and in gasoline engines. See the engine manufacturer's guide for the recommended specifications. Compare the specifications to those of Caterpillar multigrade Diesel Engine Oil. The current industry standards for Caterpillar Diesel Engine Oil are listed on the product label and the data sheets for the product.

Consult your Caterpillar dealer for part numbers and available sizes of containers.

NOTE: In addition to passing the API CH-4, CG-4, CF-4, CF oil classification tests, Caterpillar 15W-40 multigrade DEO (CH-4) also passes additional proprietary tests that include piston ring sticking, oil control, wear and soot tests. Proprietary tests help ensure that Caterpillar multigrade provides superior performance in Caterpillar Diesel Engines. In addition, Caterpillar multigrade surpasses many of the performance requirements of other diesel engine manufacturers so it is an excellent choice for many mixed fleets. **True high performance oil is produced using a combination of industry tests, proprietary tests, field tests, and prior experience with similar formulations. All these factors are used to design and develop the high performance and high quality lubricants sold by Caterpillar.**

Commercial Oils

The performance of commercial diesel engine oils is based on American Petroleum Institute (API) classifications, which are developed to provide commercial lubricants for abroad range of diesel engines that operate at various conditions.

If Caterpillar multigrade Diesel Engine Oil is not used, only use commercial oils that meet the following classifications:

- API CH-4 multigrade oil (preferred oil)
- API CG-4 multigrade oil (preferred oil)
- API CF-4 multigrade oil (acceptable oil)

NOTICE: In selecting an oil for any engine application, both the oil viscosity and oil performance category as specified by the engine manufacturer must be defined and satisfied. Using only one of these parameters will not sufficiently define an oil for an engine application.

Select an oil with a suitable viscosity and a proper performance classification.

Lubricant Viscosity Recommendations for Direct Injection (Dl) Diesel Engines

The proper SAE viscosity grade of oil is determined by the minimum ambient temperature during cold engine startup and the maximum ambient temperature during engine operation.

Refer to Table 1 (minimum temperature) in order to determine the required oil viscosity for starting a cold engine.

Refer to Table 1 (maximum temperature) in order to select the oil viscosity for engine operation at the highest ambient temperature that is anticipated.

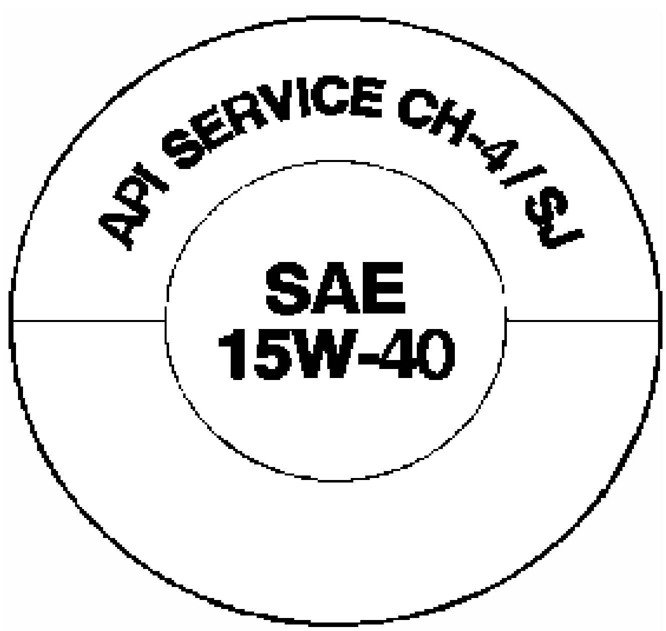
Generally, use the highest oil viscosity that is available to meet the requirement for the temperature at start-up.

Table 1

Engine Oil Viscosity		
Caterpillar DEO Multigrade API CH-4 API CG-4 and API CF-4 Viscosity Grade	Ambient Temperature	
	Minimum	Maximum
SAE 0W20	-40 °C (-40 °F)	10 °C (50 °F)
SAE 0W30	-40 °C (-40 °F)	30 °C (86 °F)
SAE 0W40	-40 °C (-40 °F)	40 °C (104 °F)
SAE 5W30	-30 °C (-22 °F)	30 °C (86 °F)
SAE 5W40	-30 °C (-22 °F)	40 °C (104 °F)
SAE 10W30	-20 °C (-4 °F)	40 °C (104 °F)
SAE 15W40	-15 °C (5 °F)	50 °C (122 °F)

The API Donut
To aid customers in selecting the appropriate oil, the American Petroleum Institute has developed the API "donut" symbol. The symbol (see drawing below) indicates the API service classification (upper half of the circle), SAE viscosity grade (center of the symbol) and, if applicable, energy conserving feature of an oil (bottom half of the circle). Energy conservation is not applicable to heavy-duty diesel engine oils.

While any oil supplier may use the API service classifications to indicate the performance level of anyone of their commercial oils, only licensed companies may use the API donut symbol on their labels. Licensees who use this donut have certified that each licensed oil meets all prescribed technical performance standards. Some monitoring is done through the SAE Oil Labeling Assessment Program (OLAP), co- sponsored by API and the U.S. Army, which analyzes a representative sample of oils in the marketplace. Therefore, for best assurance that an oil does meet the advertised performance classification, select an oil that has the API donut display.

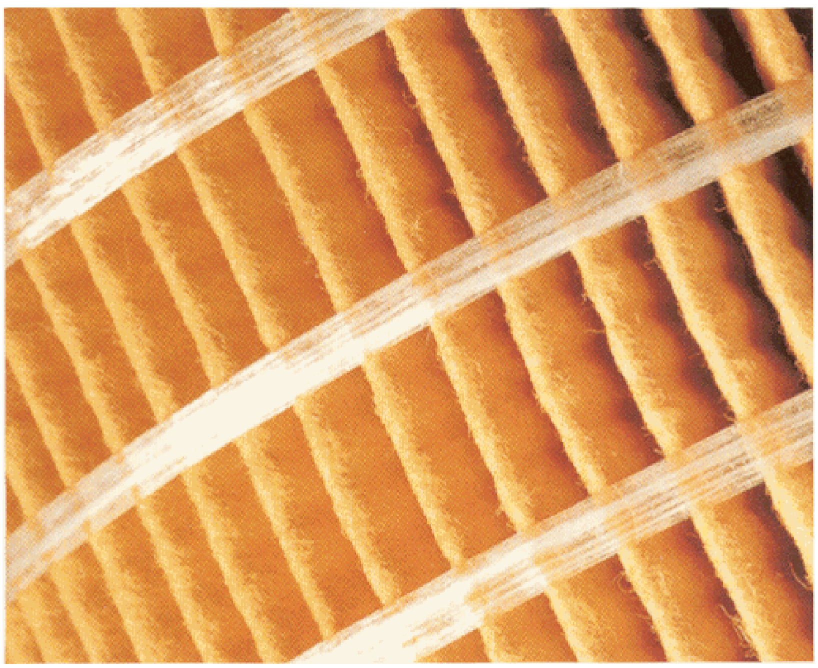


Cleanliness
Normal engine operation generates a variety of contaminants- ranging from microscopic metal particles to corrosive chemicals. If the engine oil is not kept clean through filtration, this contamination would be carried through the engine via the oil.

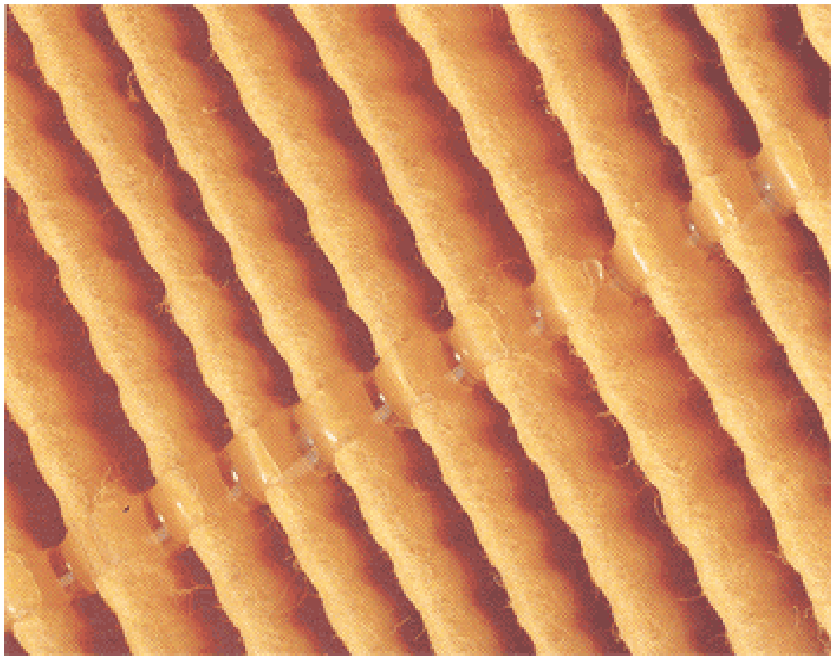
Oil filters are designed to remove these harmful debris particles from the lubrication system. Use of a filter beyond its intended life can result in a plugged filter. A plugged filter will cause the bypass valve to open, releasing unfiltered oil. Any debris particles in the oil will flow directly to the engine. When a bypass valve remains open, the particles that were previously trapped by the filter may also be flushed from it and then through the open bypass valve.

Filter plugging can also cause distortion of the element. This happens when there is an increase in the pressure difference between the outside and inside of the filter element. Distortion can progress to cracks or tears in the paper. This again allows debris to flow into the engine where it can damage components.

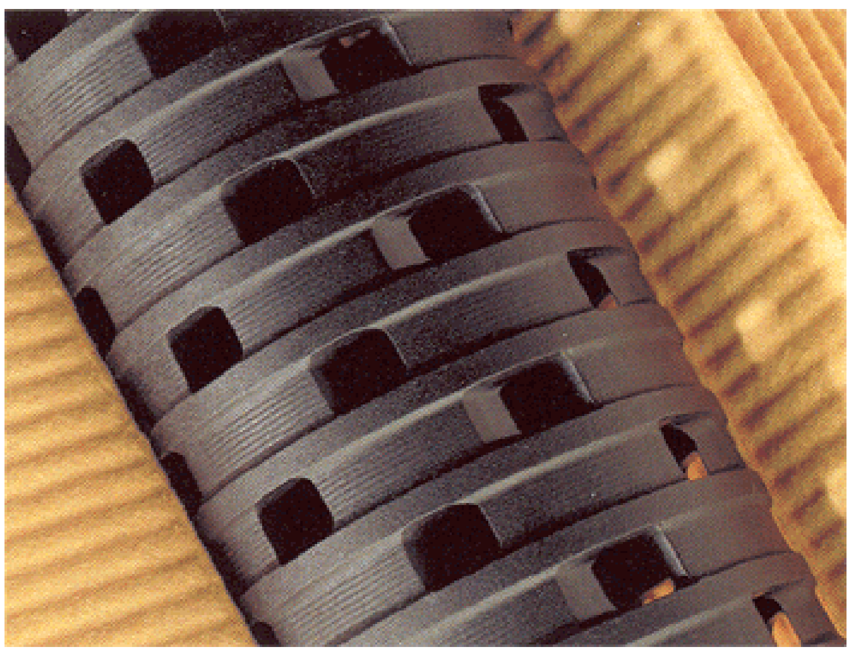
New filter element(s) should be installed any time the engine sump oil is drained and the engine sump is filled with new oil.



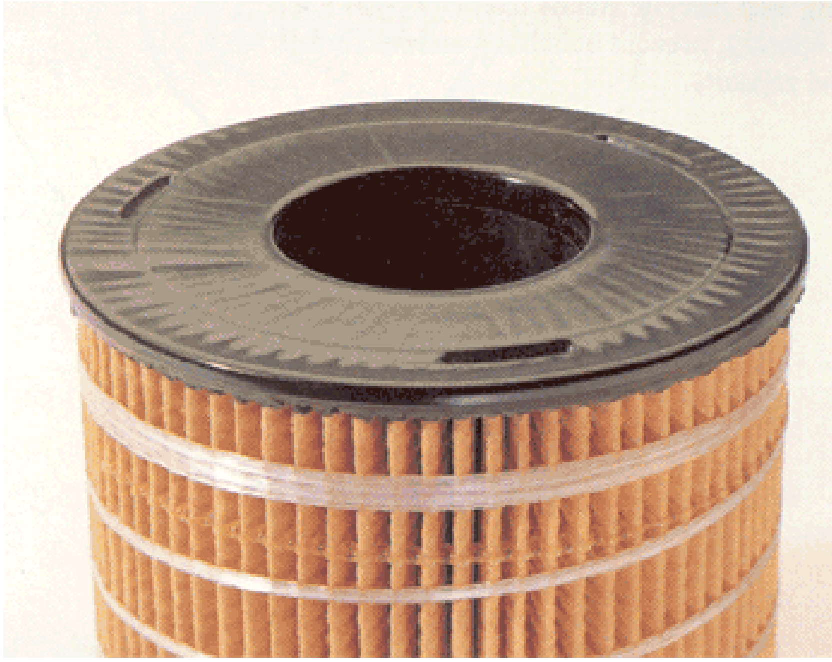
Spiral Roving and Acrylic Beads maintain pleat stability and spacing, prevent bunching, and maximize efficiency and capacity.



Proprietary Media designed to maximize engine life.



Non-Metallic Center Tube prevents metal contamination and is stronger than metal to prevent collapsing.

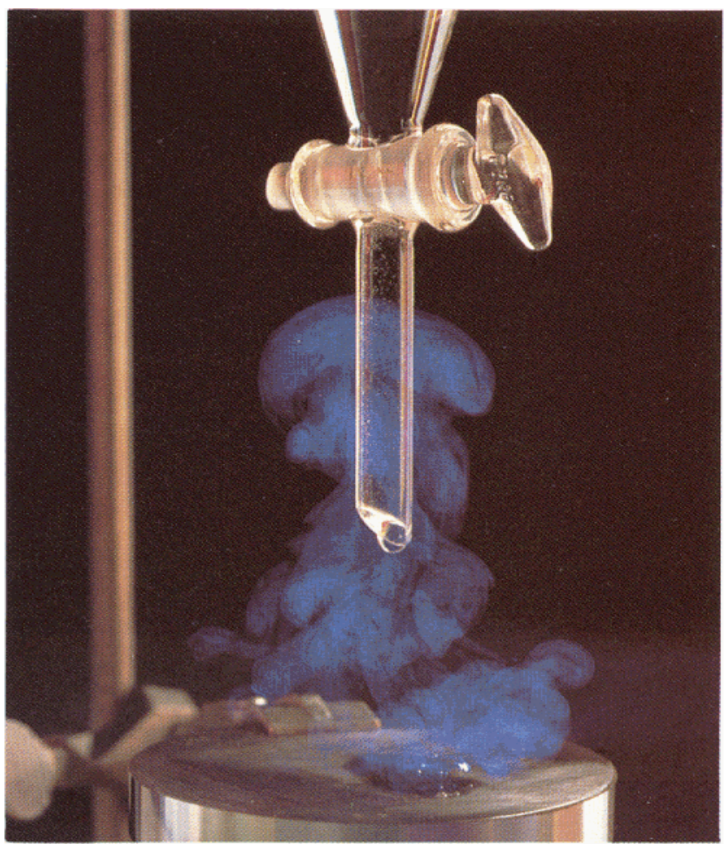


One-Piece Uretane End Caps bond tightly with filter media for greater strength.

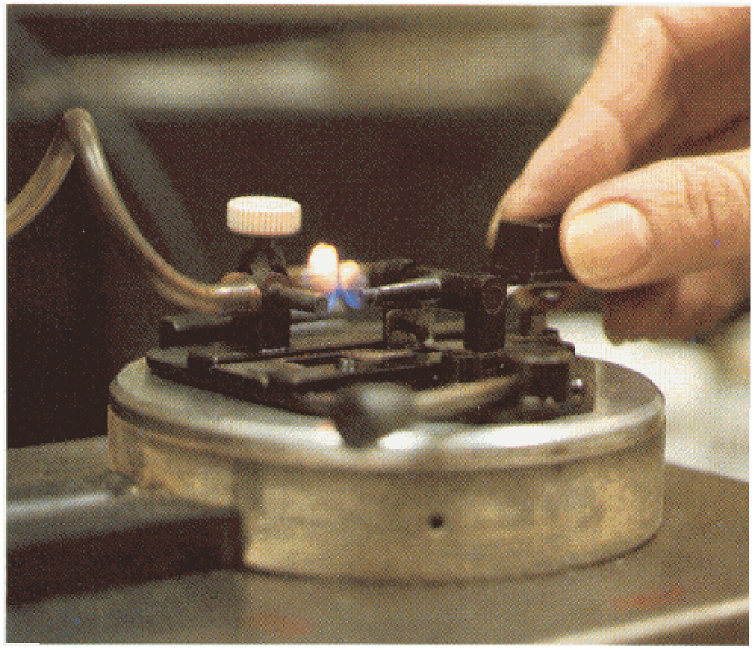
Contamination & Degradation

Taking an oil sample

Analyzing an oil sample using an inductively coupled plasma spectrophotometer.



The presence of water in the oil is verified and measured by the sputter test.



The presence of fuel in the oil is verified and measured with a Setaflash Tester.

Proper oil maintenance is imperative to keep diesel engines operating at peak performance. Oil maintenance includes scheduled oil changes and oil analysis. Oil analysis is important because the performance of engine oil slowly degrades with time. This degradation takes place as the amounts of wear metals and contaminants increase. Under severe operating conditions, the degradation process can be accelerated. For diesel engines, severe conditions are defined as one or more of the following: high load factor, excessive cycling, extended oil drains, high altitude, dusty air, prolonged idle, high sulfur fuel, and low jacket water temperatures. In either normal or severe conditions, crankcase oils eventually lose the ability to adequately lubricate and protect engine parts from accelerated wear and damage.

It is therefore important to analyze the oil at regular intervals. Caterpillar has developed a maintenance management tool that evaluates oil degradation and detects the early signs of internal component wear. The Caterpillar tool for oil analysis is called S·O·S SM Oil Analysis and it is part of the S·O·S SM Services program. S·O·S SM Oil Analysis divides engine oil analysis into three basic categories: wear rate, oil condition, and additional tests. Together, these 3 types of analysis are used to evaluate oil degradation and detect potential engine problems. A properly administered S·O·S SM Oil Analysis program will reduce repair costs and lessen the impact of downtime.

S·O·S SM Wear Rate Analysis

Prevent problems and reduce costs by knowing wear rates

Wear Rate Analysis is an integral part of our S·O·S SM Services program that helps you maintain engine performance and maximize availability. Through regularly scheduled testing of oil samples from your engine, Wear Rate Analysis detects tiny metal particles caused by component wear. By monitoring trends in the type and quantity of particles, you can get early warning of problems before major damage occurs.

Understanding wear metals

Every engine produces wear metals in everyday operation. If wear accelerates, the concentration of wear metal particles increases, signaling a problem. Wear Rate Analysis allows you to find problems before they result in major repairs or engine failure.

Wear Rate Analysis can detect particles that range up to about 10 microns in size. Wear metal concentrations are expressed in parts-per-million (ppm). The S·O·S SM Services program tests for at least 9 different substances: copper, iron, chromium, lead, tin, aluminum, molybdenum, silicon and sodium. All are wear metals found in Caterpillar engines except silicon (which generally indicates dirt) and sodium (which indicates water or coolant). Certain elements in a sample may be from the oil additive package rather than from wear within the system. Skilled dealer interpreters can tell the difference between normal elements and those that indicate abnormal wear.

Trending wear metals in your engine
Two identical engines under identical conditions may generate wear particles at different rates. Our S·O·S SM interpreters have access to a large database of samples for comparison with samples from your engine. However, your own engines may provide the best guidelines for appropriate levels of wear metals in each compartment. That's why trending is an essential part of Wear Rate Analysis. After three samples have been taken from a particular compartment, a trend for each wear metal is established. Our interpreters then compare subsequent samples to this trend line to quickly spot deviations as well as monitor gradual changes in concentration levels. This attention to trends also assists with life cycle analysis, helping you optimize productivity.

The Technology Behind Wear Rate Analysis
We use an emission spectrometer to perform Wear Rate Analysis. The spectrometer determines wear elements and silicon in a sample by subjecting the oil to very high temperatures. At these temperatures, the elements in the sample are "atomized," with each emitting a different wavelength of light energy. An optical system measures and records the light energy and calculates the results in parts-per-million for each element.

	Combinations of Classic Wear Elements			
	Primary Element	**Secondary Element**	**Potential Wear**	**Probable Problem Area/Causes**
Engines-Top End	Silicon (Dirt)	Iron, Chrome, Aluminum	Liners, Rings, Pistons	Air Induction System/Filter Dirt Contamination
	Iron	Chrome, Aluminum	Liners, Rings, Pistons	Abnormal Operating Temps., Oil Degradation, Fuel and/or Coolant Contamination, Stuck/Broken Rings
	Chrome	Molybdenum, Aluminum	Rings, Pistons	Blowby, Oil Consumption, Oil Degradation
	Iron	---	Liners, Gears, Valve Train, Crankshaft	Abnormal Operating Temps., Lack of Lubrication, Contamination, Storage (Rust)
Engines-Bottom End	Silicon (Dirt)	Lead, Aluminum	Bearings	Dirt Contamination
	Lead	Aluminum	Bearings	Lack of Lubrication, Coolant Contamination, Fuel Contamination

Pinpointing the Causes and Effects of Component Wear
By comparing infrared (Oil Condition) test results with wear metal buildup, we can pinpoint probable causes of elevated wear metals. The chart above illustrates some of the most common wear metals, their source(s), and the potential problems they indicate.

Spectrometry detects dirt contamination as well as wear metals. Silicon is the most common element indicating dirt entry, although some clay soils also produce increased aluminum readings.

Monitoring Your Components
When S.O.SSM analysis identifies an increase in the concentration of one or more metals, it can point to the wearing component most likely causing the increase and, often, the probable cause. For example, a sudden increase in silicon and iron in an oil sample would probably indicate a problem caused by either air system leaks or crankcase seal leaks (see chart above).

Silicon/Aluminum Ratio in Dirt Varies by Location
The primary constituents of dirt are minerals containing silicon and aluminum. The ratio of these 2 elements varies widely from place to place. Clay soils contain nearly as much aluminum as silicon. This is one reason why local interpretation of your sample results is important. We are familiar with the soils in your area, giving us the best understanding of the combinations of elements in your samples.

S·O·S SM Oil Condition Analysis

Maximize Performance by Knowing Your Oil Condition

Oxygen exposure, heat and contaminants cause all oils to degrade. Engine oil is particularly susceptible to degradation by sulfur, nitration, by- products of combustion, high temperatures, and water from the combustion process or condensation. Oil Condition Analysis, part of the comprehensive S·O·S SM Services program, helps prevent component damage by monitoring your oil and keeping track of its degradation. Oil Condition Analysis also allows you to correct problems that affect oil performance. The bottom. line benefit: maximum oil performance, optimum oil change intervals and reduced repair costs.

Understanding Oil Condition Analysis
Oil Condition Analysis is similar to Wear Rate Analysis with one important exception: it evaluates chemical compounds in the oil rather than wear element particles.

It works like this:

1. You submit a sample of new oil, called "reference oil," when you enroll in the S·O·S SM Services program and when you get new shipments of bulk oil. Reference oil samples are processed at no cost to you. If you are using Cat oil, new oil samples may not be necessary. Advise your S·O·S SM analyst of the viscosity of the Cat oil you use in each system; it has its own Cat oil reference samples.
2. The new oil is scanned by a special instrument using infrared light. Information is stored in the instrument's memory.
3. At each scheduled interval, you submit a sample of used oil.
4. The Oil Condition Analysis instrument focuses a beam of light through a film of used oil and records the data.
5. The instrument uses a mathematical formula to compare the used and new oils and quantify any differences.

Fourier Transform Infrared Analysis
S·O·S SM Oil Condition Analysis includes an infrared instrument that uses a mathematical method to convert raw instrument data into meaningful terms. This test, often called FT -IR (Fourier Transform Infrared Analysis), identifies and quantifies organic compound groups by measuring their infrared absorption at the specific wavelength of each group. Besides identifying oxidation, soot, sulfur products and nitration, the test is also used to scan for oil contamination by fuel, water or glycol (engine coolant).

Identifying Oil Condition Before It Causes Problems
Oil Condition Analysis detects soot, oxidation and nitration products and sulfur products/acids. This test can also detect contamination by water, fuel and glycol from coolant. If detected, specific contaminant tests are used to confirm findings. Oil Condition Analysis focuses on:

Soot
Soot is the insoluble residue of partially burned fuel. It is held in suspension by the oil additive package and causes engine oil to turn black. When soot drops out of suspension in the oil, it contributes to additive depletion and eventually increases oil viscosity. Heavy concentrations of soot can cause bearing damage by starving contact surfaces of lubrication.

Oxidation
Oxidation occurs when oxygen molecules chemically join with oil molecules. This chemical reaction is accelerated by high oil temperatures, glycol contamination from engine coolant, the presence of copper and from extended oil change intervals. Oxidation causes the oil to thicken, form acids, and lose lubrication qualities, which threatens the life of your components. Oxidized oil will cause deposits on engine pistons and valves, stuck rings, and bore polishing.

Nitration Products
Nitration occurs in all engine oils but is generally only a problem in natural gas engines. Nitrogen compounds from the combustion process thicken the oil and reduce its lubricating ability. If nitration continues unchecked, it can result in filter plugging, heavy piston deposits, lacquering of valves and pistons, and eventual failure.

Sulfur Products/Acids
Sulfur is present in all fuels and affects all engines. During combustion, fuel sulfur oxidizes then combines with water to form acid. Acid corrodes all engine parts but is most dangerous to valves and valve guides piston rings and liners.

Optimizing Your Equipment with the S·O·S SM Services Program
Oil degradation may be the result of a number of factors and conditions, including extended oil change intervals, abnormal temperatures, or contamination by fuel, water or coolant. Lower quality oils will degrade more rapidly than a premium quality lubricant.

With Oil Condition Analysis, you can determine the extent to which oil has deteriorated during use and verify whether it is performing up to specification during the entire oil change period.

Oil Condition Analysis is just one part of the S·O·S SM Services program that provides information to reduce downtime and save you money by preventing major engine problems.

Additional Tests: Glycol, Water, Fuel Detection, Viscosity, and TBN
Additional oil analysis tests may be required to better define the condition of used engine oil. If the FT - IR results show the presence of glycol, water, or diesel fuel, additional testing will be needed to measure the quantity of these contaminants in the oil. Also in some cases, severe conditions may warranty the need for additional oil tests. These additional tests enhance the information already gathered in the Wear Rate Analysis and Oil Condition Analysis.

Glycol (Coolant)
Glycol causes rapid oxidation of the oil and usually indicates a cooling system leak. Severely oxidized oil becomes sticky and forms sludge that plugs the filter. Any amount of glycol contamination in the oil is unacceptable. Engines using water-to-oil coolers may become contaminated with coolant if a leak develops in a cooler tube or seal.

Water
If infrared analysis indicates the presence of water, the approximate amount is determined by placing a drop of oil on a plate heated to between 2300-250° F. If water is present, the oil will bubble and sputter. By comparing the amount of bubbling to laboratory control samples, experienced laboratory technicians can determine the quantity of water in the sample. Any amount over 0.5% is considered excessive.

Water can contaminate a system by leaking in from the outside or condensing in the engine's crankcase or compartment. When water combines with oil, it reduces the oil's ability to lubricate and forms a sludge that plugs filters. Water passing between very close components can create "hot spots." If the water gets hot enough, it causes tiny steam explosions that can fracture metal.

Fuel
Fuel contamination is confirmed using a flash test in which the used oil is heated to a prescribed temperature in a closed cup, then subjected to a flame. Fuel vapors driven off by the heat will flash.

Fuel in the engine oil reduces its lubricating properties. Small amounts of fuel are common as a result of the combustion process. But if fuel levels exceed 4% we will suggest a check for defective fuel injection nozzles and other sources of leakage. Fuel dilution is generally the result of extended idling, incorrect timing, or a problem with the fuel injectors, pumps or lines.

TBN
All diesel fuels contain some sulfur. How much depends on the amount of sulfur in the crude oil and/or the refiner's ability or desire to remove it. One of the functions of lubricating oil is to neutralize sulfur by-products (sulfurous and sulfuric acids), as well as organic acids formed by oxidation. In this way, the oil helps prevent corrosive damage. Additives in the oil contain alkaline compounds formulated to neutralize these acids. The measure of reserve alkalinity in the oil is known as the Total Base Number (TBN). Generally, the higher the TBN value, the more reserve alkalinity capacity the oil contains.

Sulfuric and other acids signal danger to metal engine parts, causing corrosive wear to the surfaces of valve guides, piston rings and liners. The type of corrosive wear attributed to high sulfur content fuel can also accelerate oil consumption. Because the level of sulfur oxides in a used oil increases with a longer oil change interval, checking the TBN of oil is important. The TBN of the oil should be checked for each oil sample.

Engine jacket water outlet temperature influences the formation of corrosive acids. Even when using a fuel with less than 0.5% sulfur coolant temperatures below 82.2° C (180° F) can cause acid vapors to condense in the engine oil system and corrosive attack occurs. Low temperatures also increase the amount of water condensation which otherwise might have evaporated out of the oil at normal operating temperature. This residual water depletes certain oil additives and reduces the oil's ability to protect engine parts. This causes deposits, sludge formation, lacquering, varnish and carboning. In applications where humidity is high, acids are more likely to form because of the additional water in the air. So, both low coolant temperature and high humidity can result in increased corrosive attack.

Viscosity
Viscosity is defined as a measure of a fluid's resistance to flow. The standard measure of this property for crankcase oils is termed "kinematic viscosity." Kinematic viscosity is based on the ability of an oil to flow under the influence of gravity through a capillary tube. The test for kinematic viscosity is defined by ASTM 0445.

Crankcase oil may begin to lose its lubricating properties after experiencing a 3 cSt. Change. An oil which has experienced a viscosity change of this magnitude should not be continued in use because damage to the engine may occur.

There are 2 most frequent causes for an increase in crankcase oil viscosity. The first is an accumulation of combustion by-products (mainly soot) which can thicken the oil. The second is heat, which can cause oxidation. Also, oxidation, with resultant oil thickening, can occur if engine coolant (glycol) enters the crankcase. Water from condensation or contamination can also contribute to oxidation.

There are two primary reasons an oil might experience a decrease in viscosity. The first is fuel dilution, which is not a failure of the oil but a contamination problem that must be resolved promptly. Another possible reason for a viscosity decrease is shearing of the long-chain polymer molecules that comprise the viscosity improver additives. In such an instance, the oil can no longer maintain performance at higher temperatures and migrates toward the lower viscosity of the base stock mineral oil. In either case, fuel dilution or shearing, the oil can "thin down" to the point it can no longer maintain an adequate oil film at operating temperatures.

When investigating a change in oil viscosity be alert to the possibility that the wrong oil was used during an oil change or as make-up oil. Careful analysis of FT -IR test results can help determine this possibility.

An oil that has experienced a 3 centistoke change has been used beyond its useful life. An increase in wear metal debris will probably be detected in samples of oil which have experienced this amount of viscosity change.

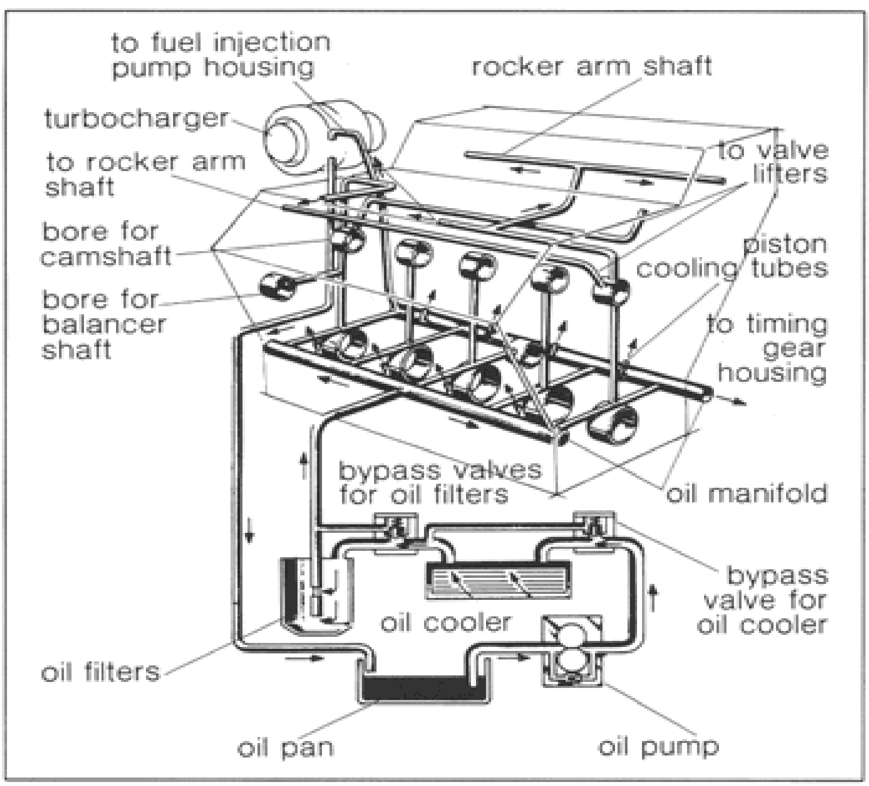
Typical Examples of Oil Related Failures

The Lubrication System
A basic understanding of the engine lubrication system is not only helpful in understanding how oil contamination/degradation can damage engine components but also in understanding how alack of oil can have an equally debilitating effect.

Most oil-related failures are caused either by contaminated or degraded oil flowing through the engine or by oil failing to flow to a given component. Knowing how the lubrication system "feeds" the engine can simplify failure analysis. An example of this would be a bearing failure due to lack of lubrication. If the failure is discovered early, the bearings farthest from the oil supply may show the greatest damage.

The lubrication system for each engine may differ slightly; however, most principles are the same. The lubrication system for the 3408 Engine is similar to other engine lubrication systems. As shown in the schematic, the oil pump sends oil through the oil cooler and then through the oil filters. The bypass valves for the oil cooler or oil filters protect the system if there is a reduction in the oil flow. When the engine is started with cold oil, or if the cooler or filter becomes plugged, the bypass valves assure a constant flow of oil to the engine oil passage.

Oil from the filter flows into the block oil manifold. This oil then flows into the various block oil passages to lubricate and cool the various engine components; then it returns to the oil pan.



The lubrication system of a 3408 Engine.

Bearings
Oil-related bearing failure is usually attributed to one of two sources: lack of lubrication or dirt in the oil.

Lack of lubrication or oil starvation refers to an insufficient oil film between the crankshaft journal and bearing. Prolonged operation of an engine with an insufficient oil film will cause damage to progress quickly to a smeared bearing, then to a scuffed bearing, and finally to a seized bearing. The first stage of this type of damage is smearing. This stage will show displacement of the lead-tin overlay, normally in the center of the bearing.

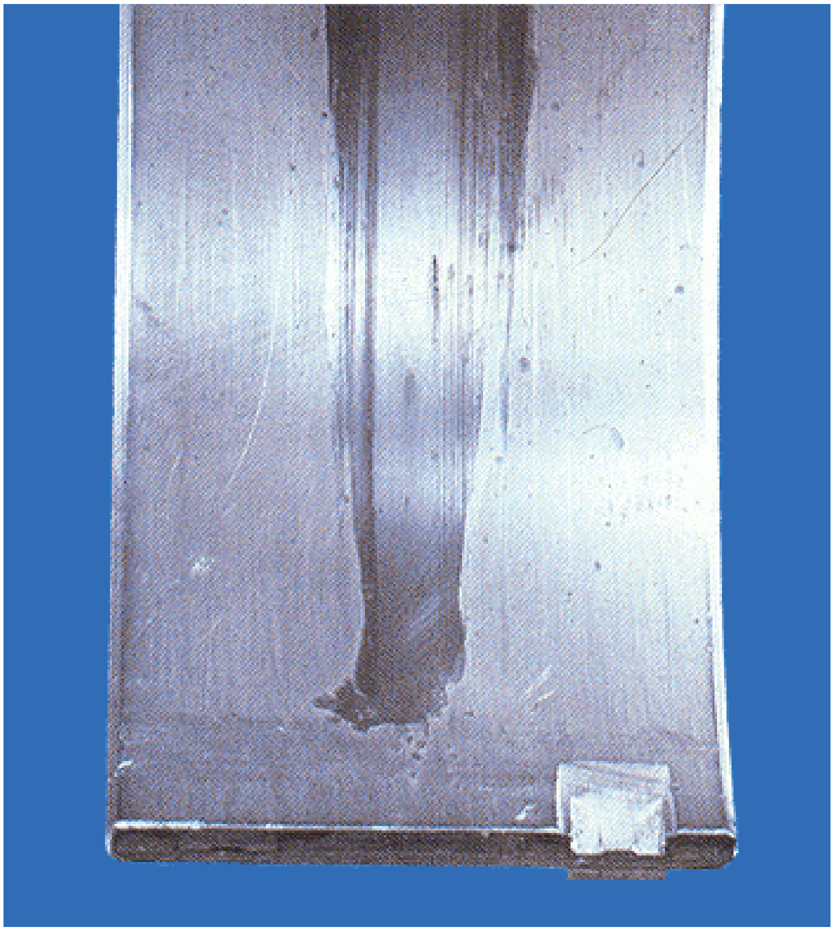
In the second stage of damage, scuffing, the aluminum in the center of the bearing is displaced. The final stages of failure result in total seizure.

In all three stages the rotating journal displaces some of the bearing material from the crown toward the mating face of each bearing half. The amount of displaced material will depend on how severe the lack of lubrication is.

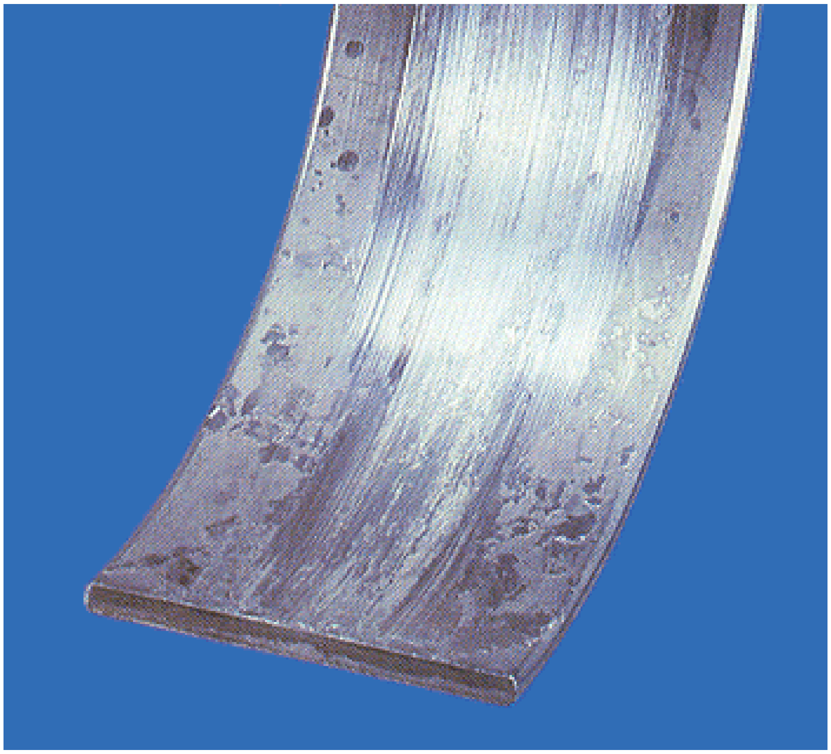
Contamination in the oil causes abrasion and results in scratching the bearing surface by wiping aluminum, plastic wood, cloth, etc. can also attack the journal surface. As the bearing and journal surfaces wear, clearances increase and oil film thickness changes, resulting in uneven support of the surfaces.

A major source of debris-Iaden oil is a plugged filter. Plugged filters allow unfiltered oil containing wear particles, dirt and debris to flow to the bearings, scratching and damaging their surfaces.

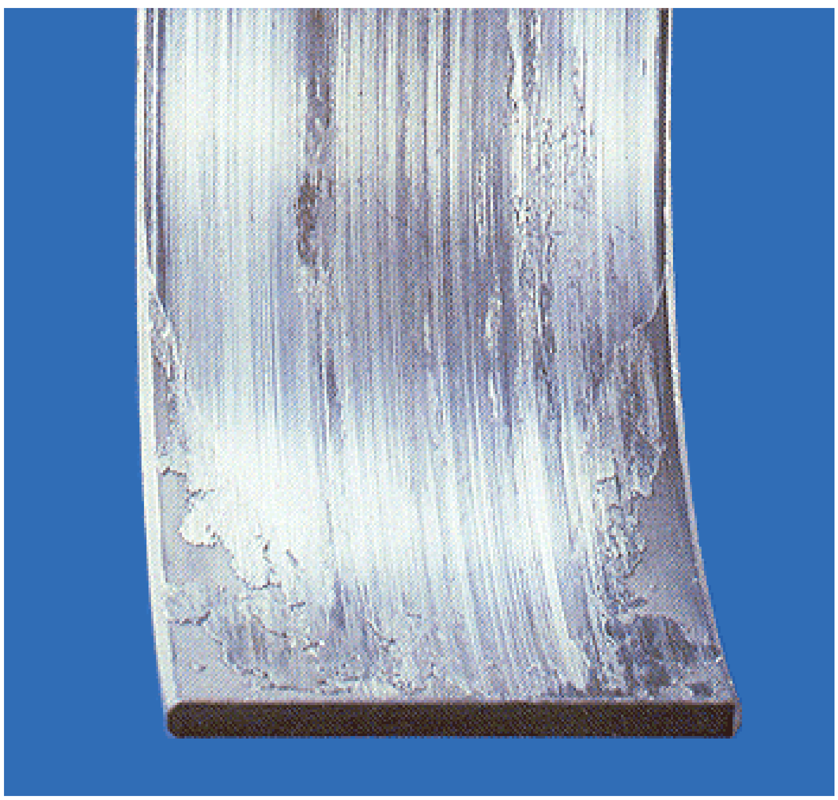
Excessively dirty oil can cause damage even after changing oil. Some old abrasives may remain embedded in the bearings and cause the bearings to act like a grinder on the crankshaft. See the next section, "Minimizing the Occurrence of Oil-Related Engine Failure," for examples of crankshaft damage.



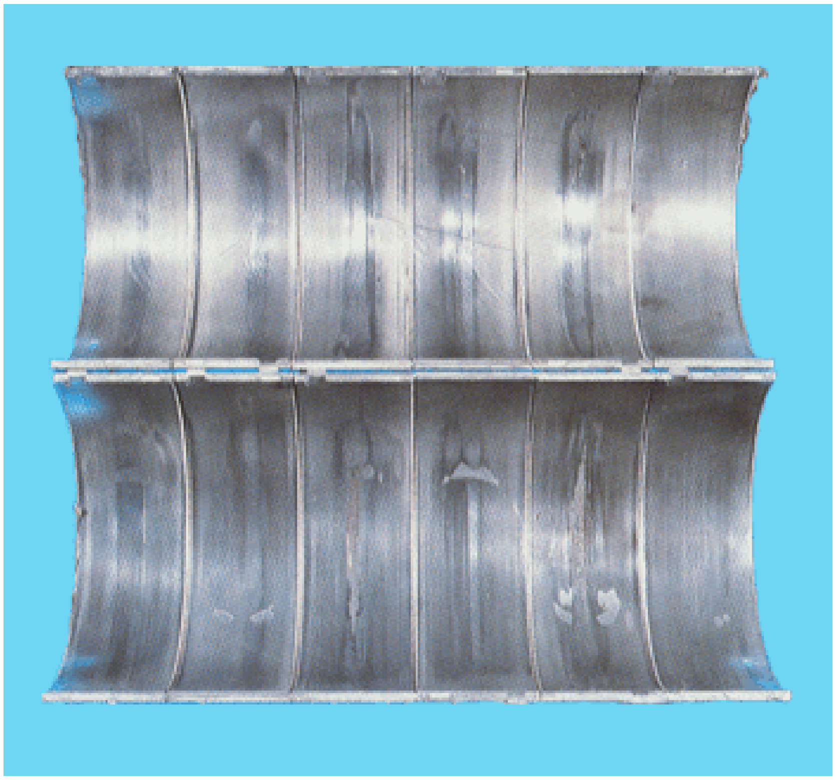
Bearing shows smearing, which is the initial stage of damage caused by lack of lubrication.



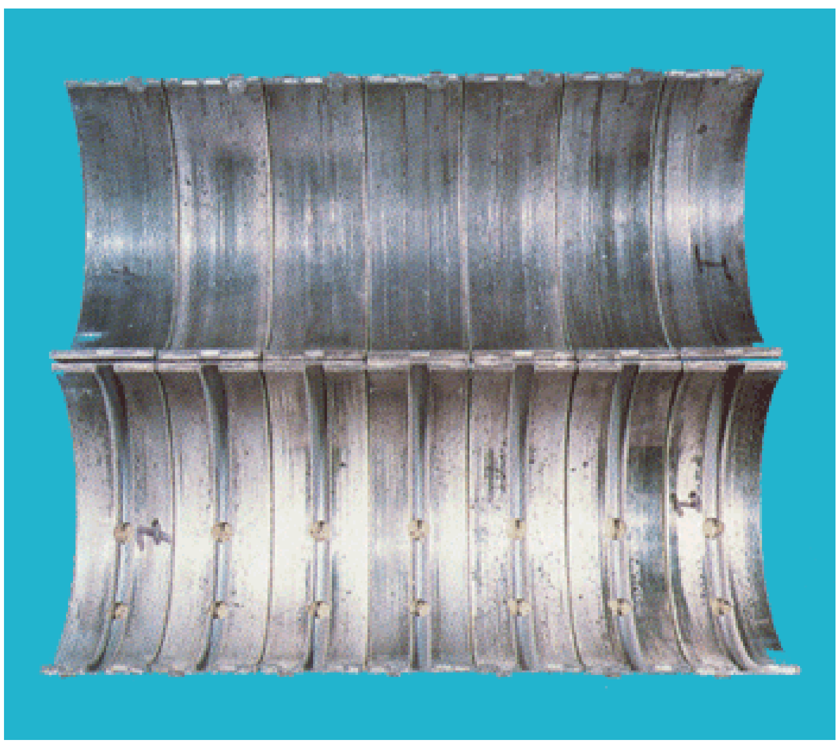
Scuffed rod bearing with more severe damage as a result of lack of lubrication.



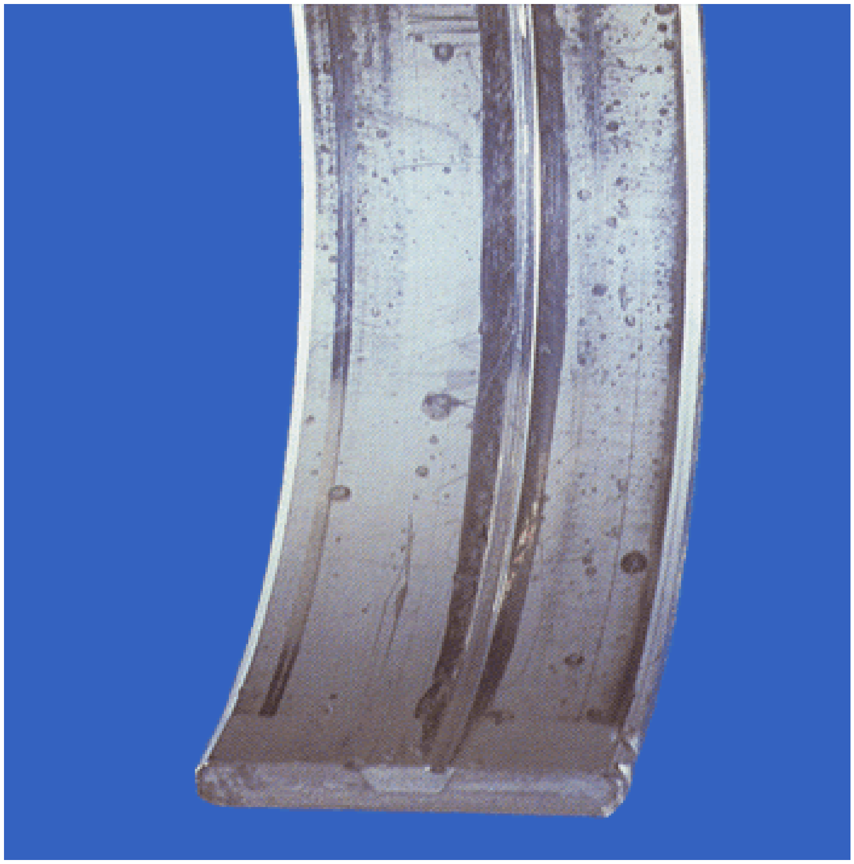
Seized bearing, which is the final stage of lack of lubrication damage.



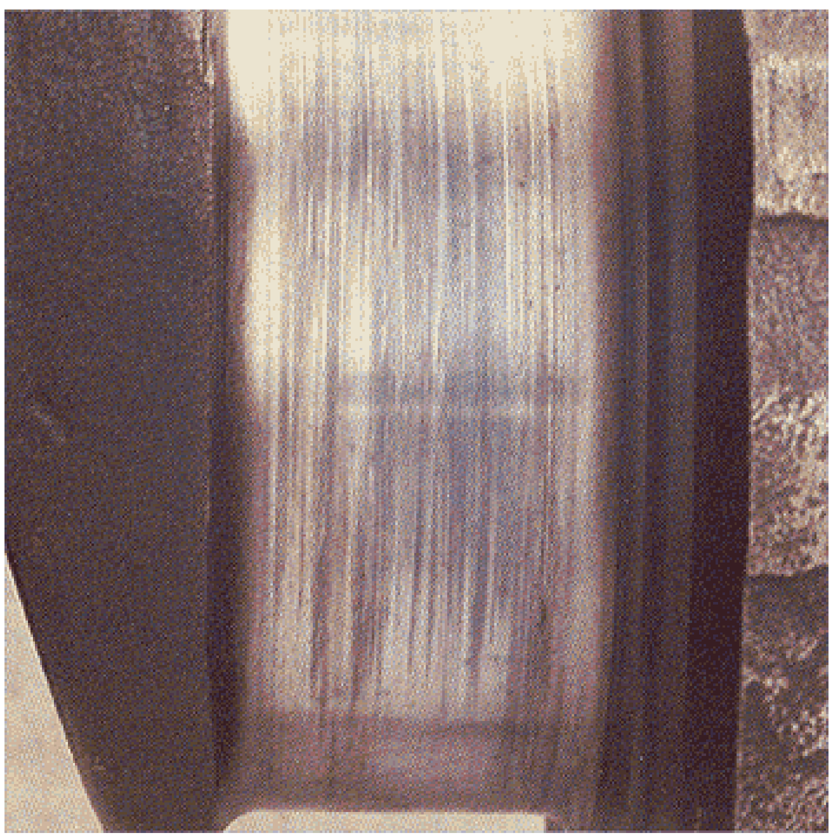
Very heavy scratches and wear caused by lack of oil. Some of the lead-tin overly has been lost.



Set of main bearings that were damaged by debris. The bearings have all stages of damage.



Scratched bearing surface. Notice embedded particles of debris.

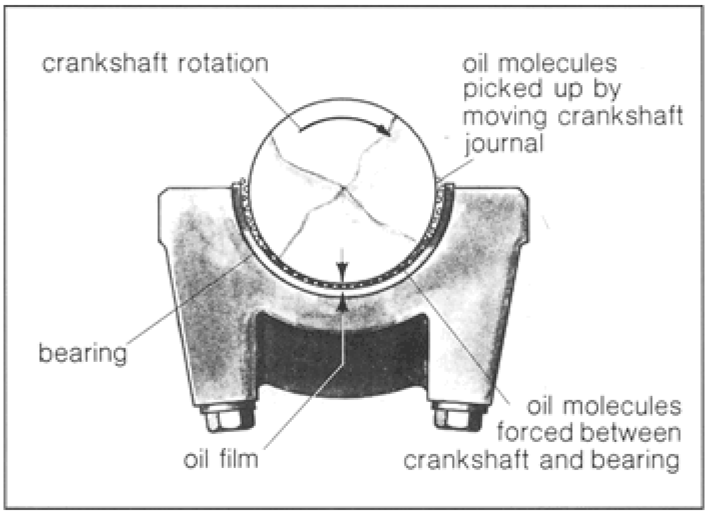


Scratches and wear on journal surface.

Crankshafts
The oil that flows to the bearings forms an oil film between the crankshaft journal and bearing. Rotation of the crankshaft journal tends to force oil between the journal and the bearing and, during normal operation, prevents metal-to-metal contact as the pressurized oil develops.

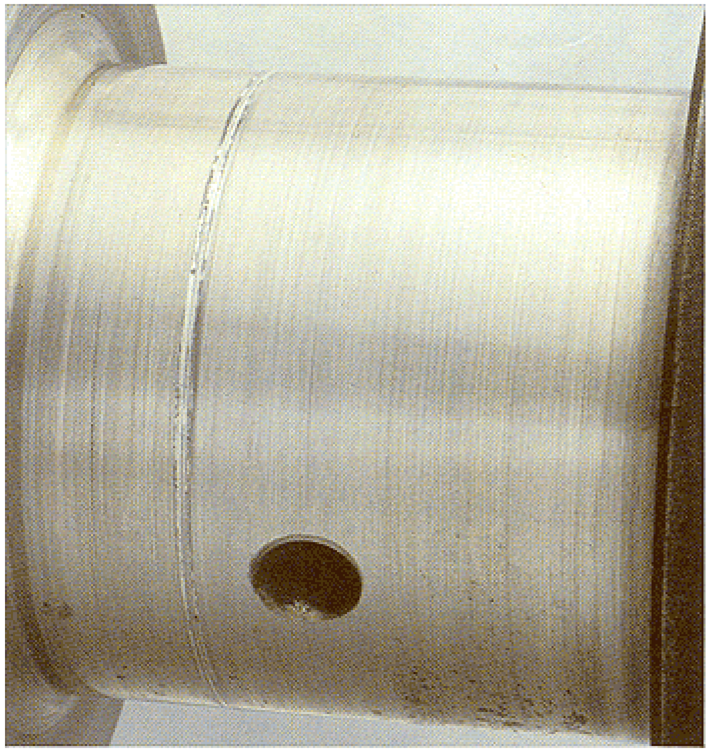
Lack of lubrication, or oil "starvation," causes metal- to-metal contact, increased friction, and higher temperatures that lead to the bearing seizing to the shaft. In extreme cases the bearing surface will adhere so tightly that the crankshaft surface will be completely destroyed.

Contaminated oil also causes excessive wear of the crankshaft. This is almost always a result of abrasives/contamination embedded in the bearing.



Oil film between crankshaft journal and bearings.


Result of oil starvation.



Deep circumferential scratches shows effects of abrasives embedded in the bearing surface.

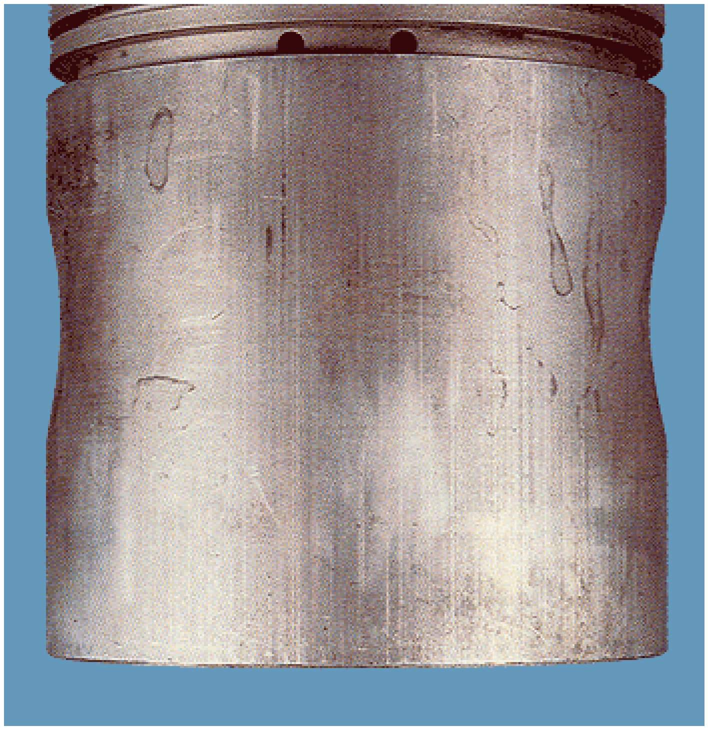
Pistons, Rings and Liners

Oil-related piston failure is most commonly caused by the abrasive action of contaminated oil which results in wear of the piston skirt. Indications include a very dull gray piston skirt, chrome facings worn off on all rings, oil ring rails worn away, badly worn grooves and some liner wear.

Piston scuffing, which appears in streaks on the skirt, particularly in the pin bore area, and little or no scuffing on the first land, may be caused by inadequate liner lubrication. Breakdown of oil film can produce seizure marks.

Piston rings can show wear in the spring groove. Some spring groove wear is normal, but neglected oil changes will cause severe ring "lock-up" that occurs when the spring catches in a worn groove and prevents full expansion.

Liner damage can be caused by lack of lubrication or by abrasives which can polish the bore (remove the crosshatch pattern) and leave a shiny surface.



Piston skirt damaged by abrasive wear.

Seizure marks from top to bottom can indicate a cooling or lubrication system failure.

Wear caused by no lubrication for a short period of time.

The heavy first and second land deposits indicate the oil can no longer keep the piston clean. The extreme degradation and deterioration of the oil maybe due to extended oil change intervals or improper oil performance classification selection.

Shiny areas on the inside liner surface caused by heavy deposits on the piston lands.

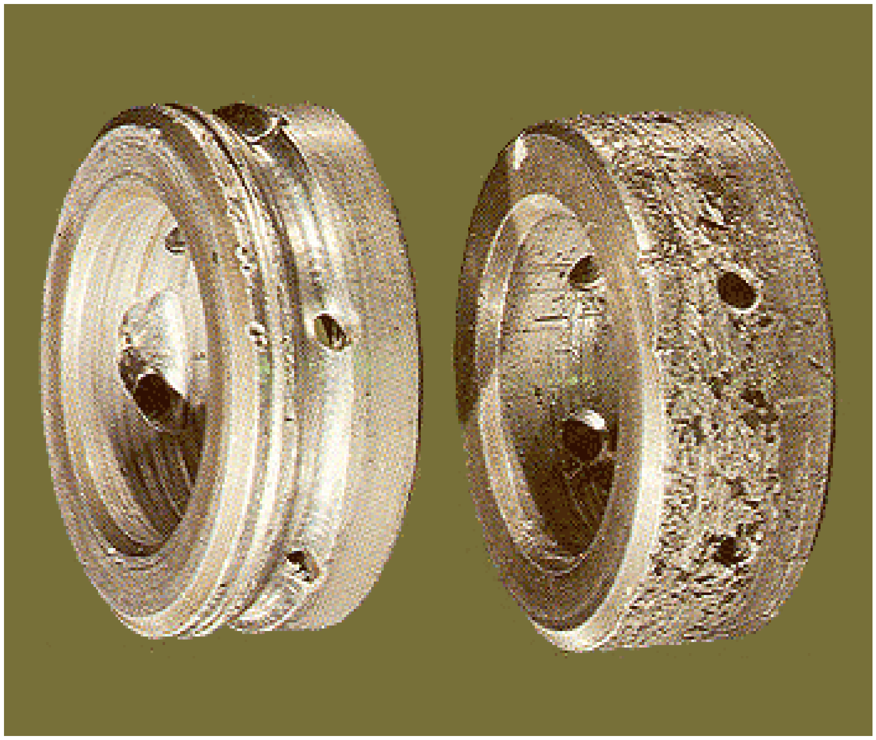
Turbochargers

Oil-related turbocharger damage is caused by oil contamination or lack of oil that can be related to operating practices. The oil supplied to the turbocharger is required to provide bearing (both journal and thrust) lubrication and also for cooling the bearing, particularly on the turbine end.

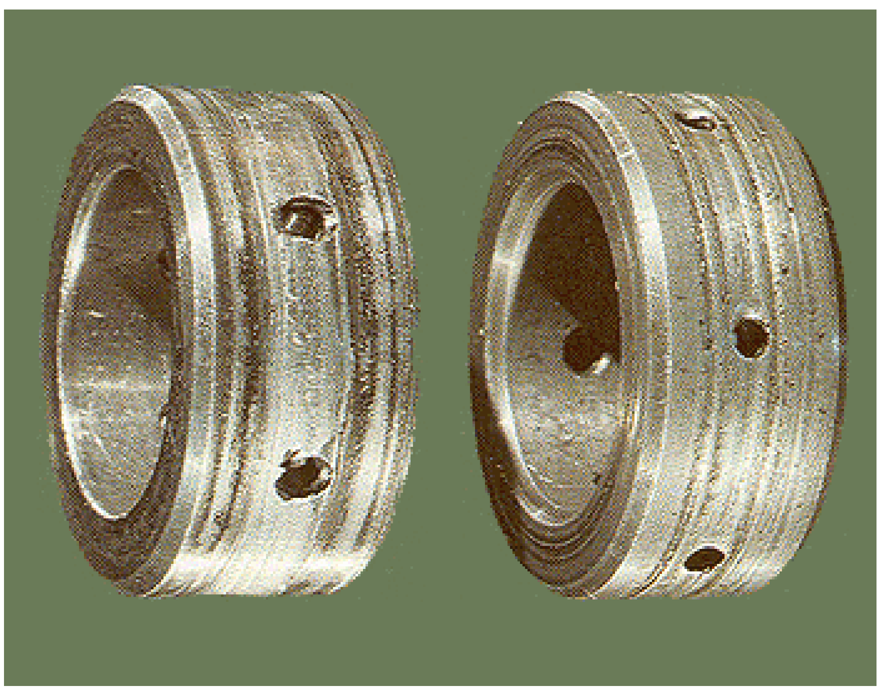
In operating the engine, startup and shutdown practices can aggravate turbocharger bearing failures. When starting the engine, particularly at colder ambient temperatures when the oil is more viscous, allow a short idling time. This idle time will allow the oil to warm up for proper filtration and flow before high engine and turbocharger speeds are attained. On engine shutdown, a short time at idle speed will allow the flowing oil to cool the turbocharger bearing housing. Without the cooling period, the oil will oxidize or coke, creating deposits on bearing surfaces and in oil passages which can restrict oil flow on the next operating period.

Oil contamination can erode oil holes and can scratch and wear bearing surfaces as well as damage shaft and housing surfaces. The lack of oil for proper lubrication will cause bearing surface damage and also cause metal discoloration due to increased temperature.

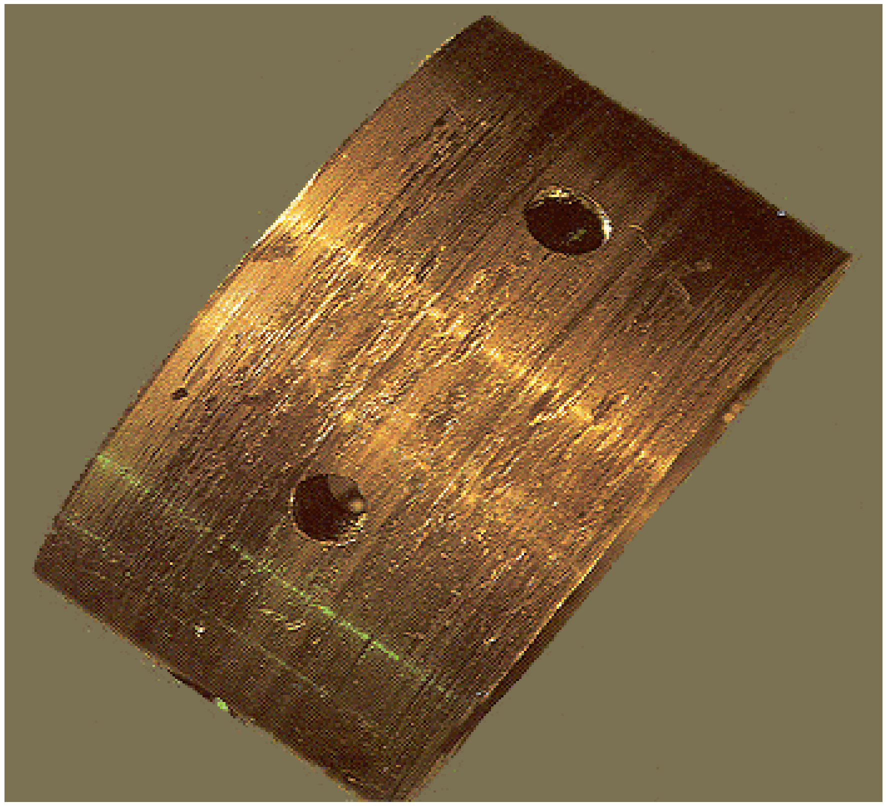
Damage to the turbocharger bearings from contamination or lack of lubrication allows motion of the shaft that permits the compressor wheel to contact its housing. Typical contact damage caused by shaft motion will be indicated by face rubbing on a few blades near their inducer section. On the back of the wheel, 180° from where the face rubbing appears, there will be some evidence of contact with the center housing.



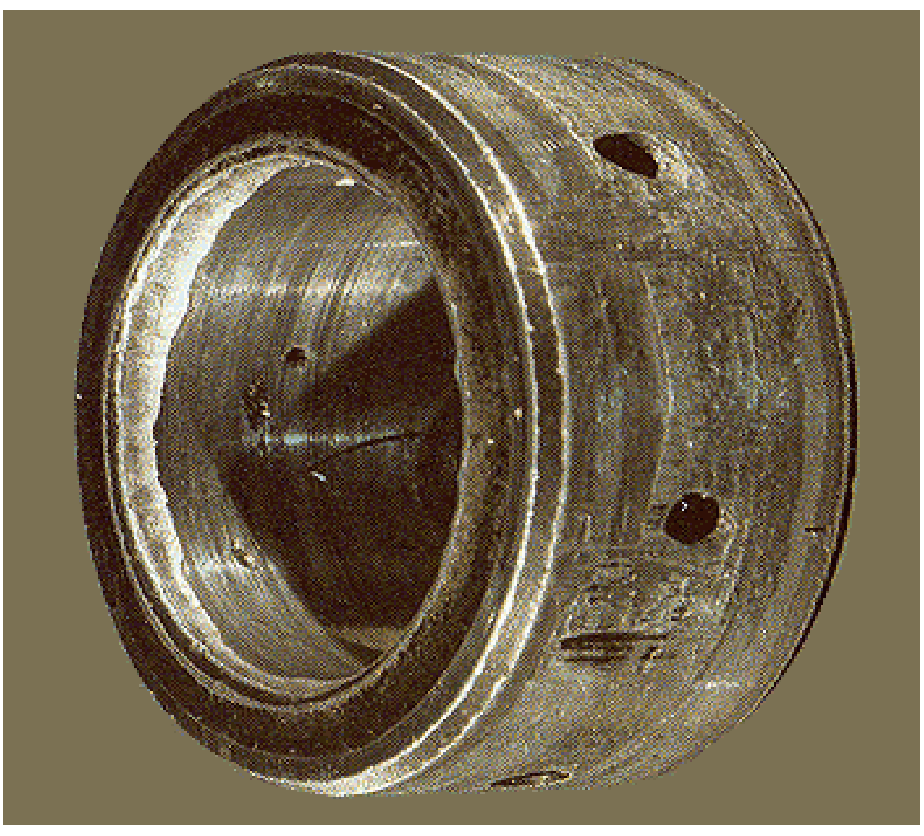
Deep scratches and damage to oil holes on bearings.



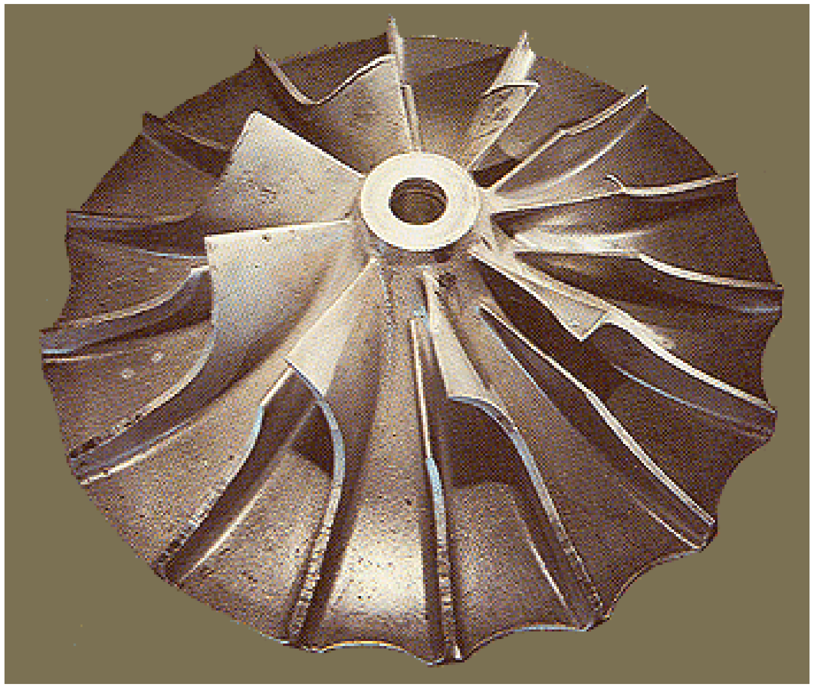
Damage from large abrasive particles in oil. Large, wide grooves around the journal bearings indicate that big particles, such as steel chips, have gone through the turbocharger lubrication oil.

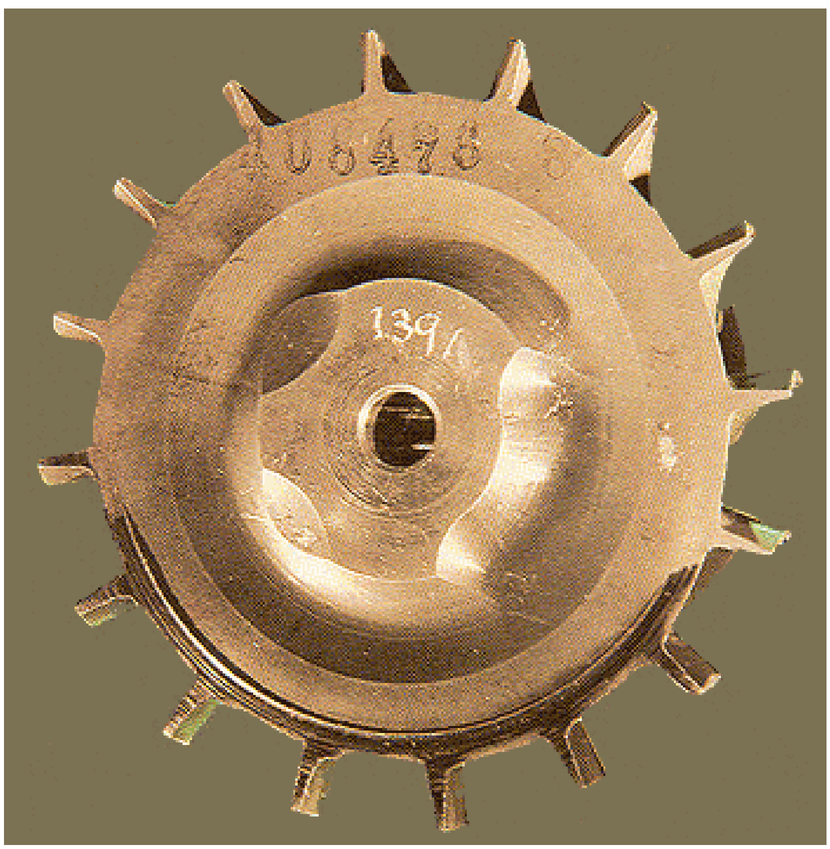


Lack of lubricant caused this journal bearing to be deformed.



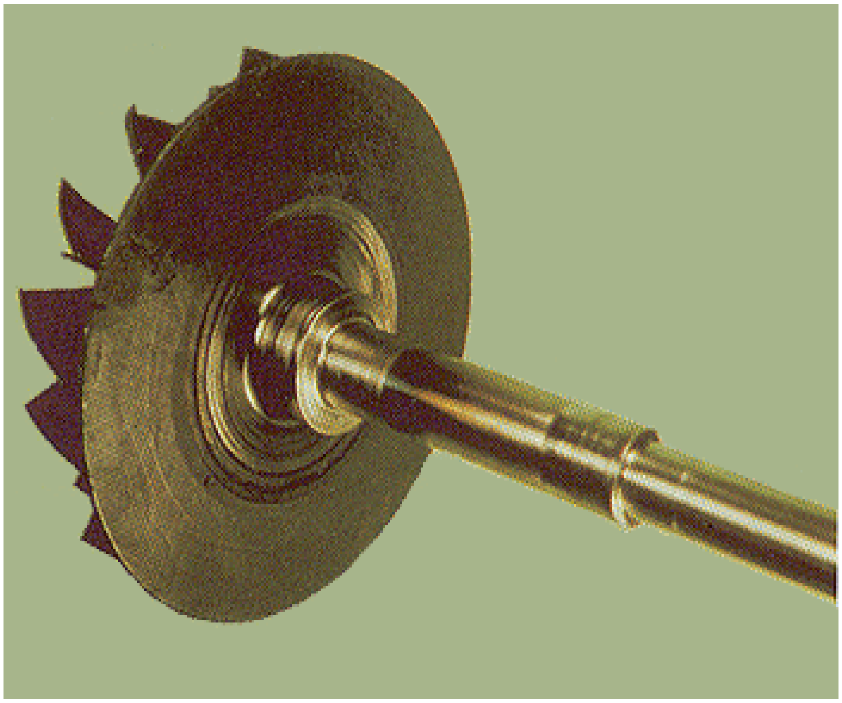
Oil holes damaged on the O.D. and reduced in size on the I.D. of journal bearing due to lack of lubricant.



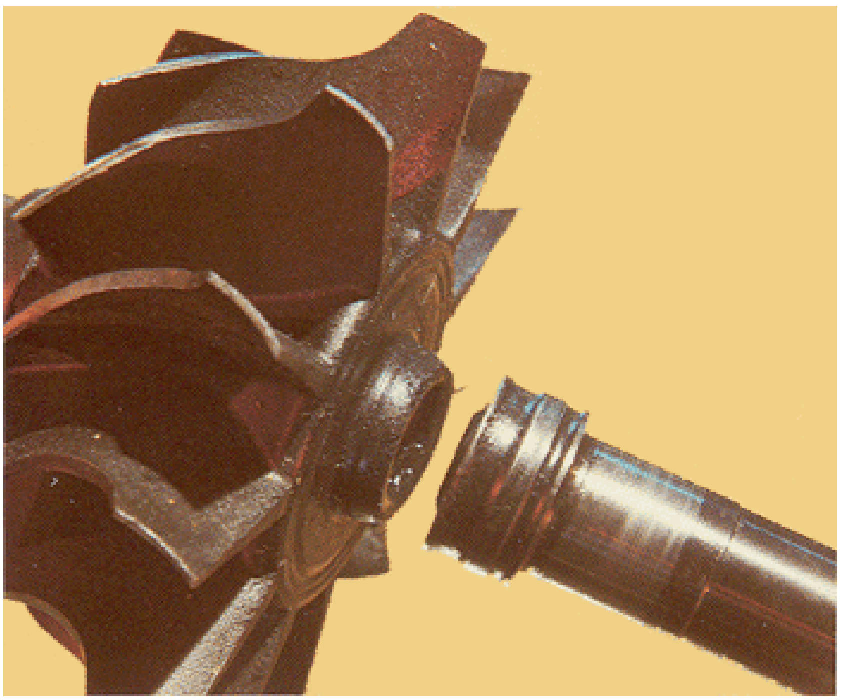


Rubbing on face and back of compressor wheel. This is caused by shaft motion due to imbalance or shaft bent at assembly.

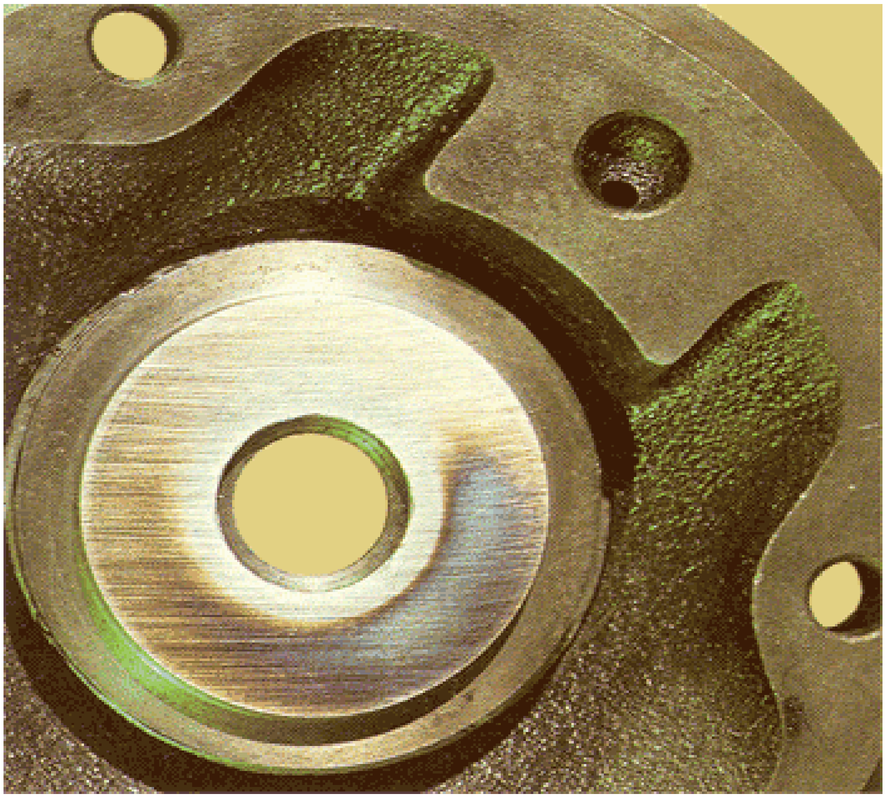
Lack of lubricant and contaminated oil both cause wear on thrust bearings, making it difficult to pinpoint the cause of failure. Checking journal bearing condition will help determine the exact cause of the failure. Heat discoloration of thrust rings also points to lack of lubrication. On AiResearch turbochargers, distortion is most commonly seen on the inboard side of the thrust rings. On the Schwitzer models, discoloration tends to be confined to one area of the ring face. Often, rubbing marks are present. Damage appears on both rings.



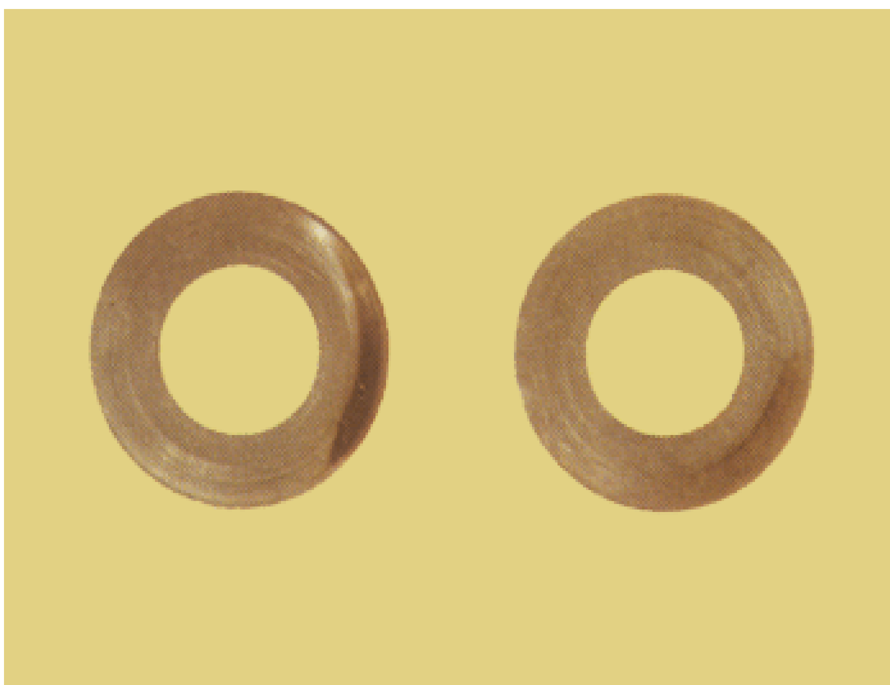
Heat discoloration on the shaft.



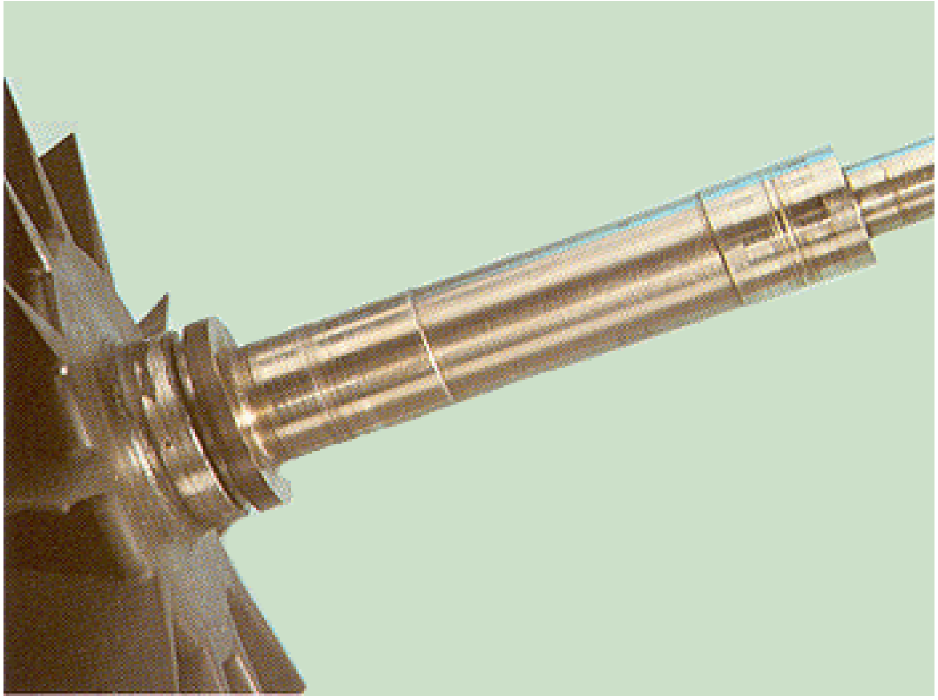
Shaft broke when contact on turbine hub, due to thrust bearing failure, weakened.



Heat discoloration on inboard side of thrust ring (AiResearch).

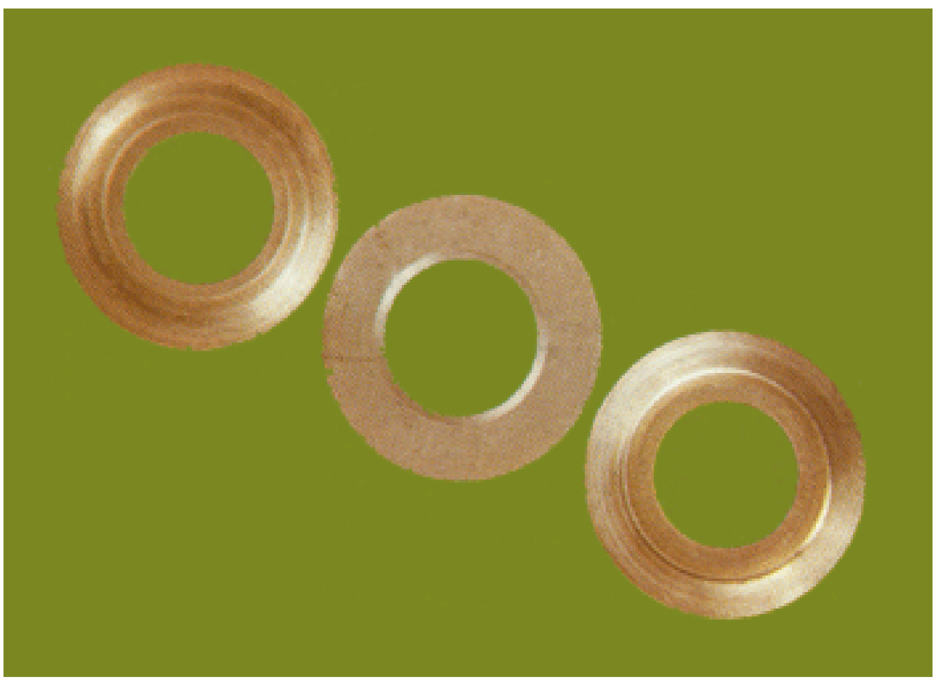


Heat discoloration and rubbing marks confined to one area on face of both rings (Schwitzer).

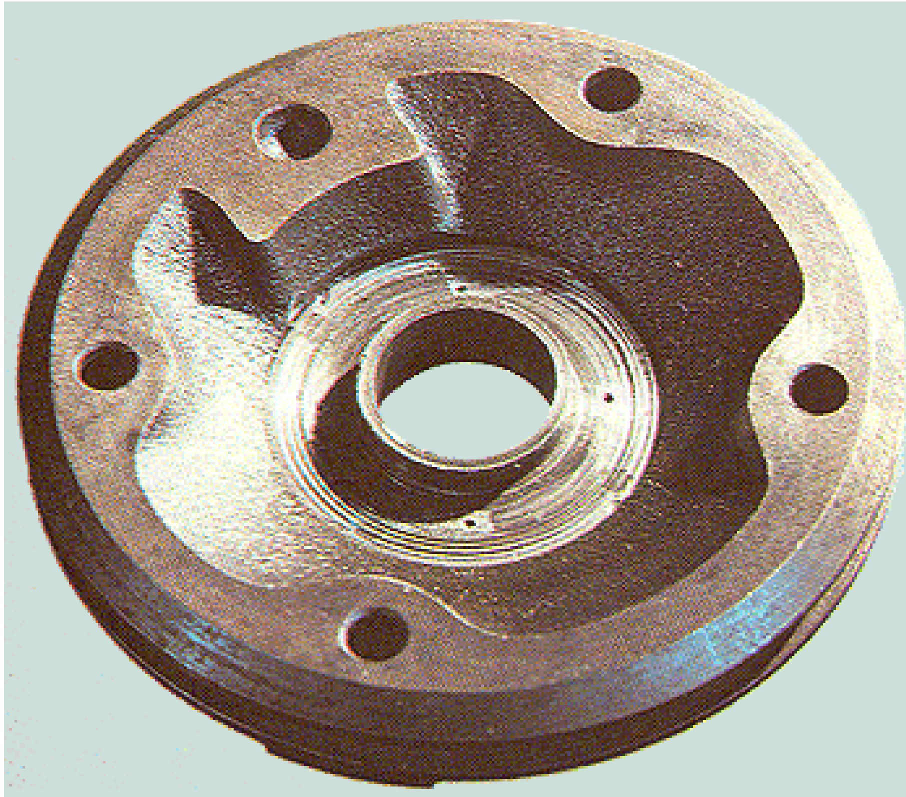


Scratches on both bearing journals...dirty oil.

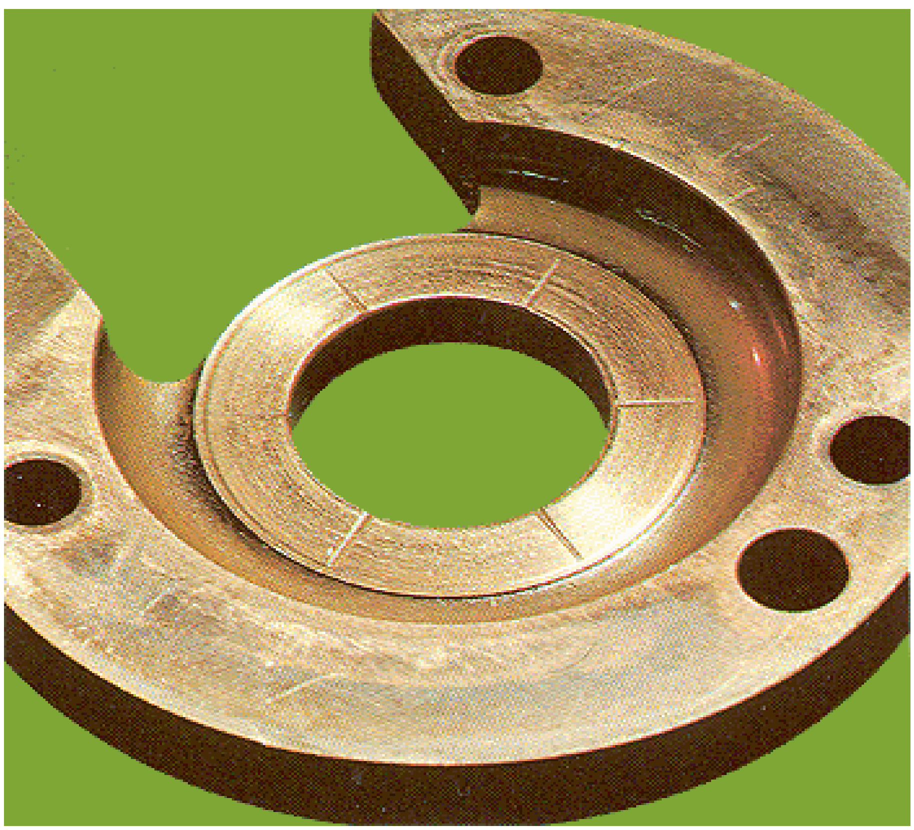
Bearing damage and excessive shaft motion caused by lack of lubrication or abrasives in the oil may eventually cause the shaft to bend or break. Generally, parts worn by abrasives will look eroded As a rule, the bearing surfaces will not look smeared and parts will show no heat discoloration. Of the illustrations, the first typifies wear from foreign material in the lubricating oil; deep grooves are worn into the two steel thrust washers. The second shows abrasive wear on the AiResearch turbocharger; deep grooves are worn in the thrust washer. The damage in the third illustration is harder to identify. It is very fine abrasive wear, which makes the thrust bearing surface look polished, and there is no heat discoloration.



Schwitzer. Wear grooves on mating surfaces of thrust washers. Center washer is new thrust washer.



AiResearch. Wear grooves on surface of thrust washers.



Schwitzer. Thrust bearing surface polished by fine abrasives in the oil.

Valves

Most oil-related valve failures result from deposit formation or oil starvation.

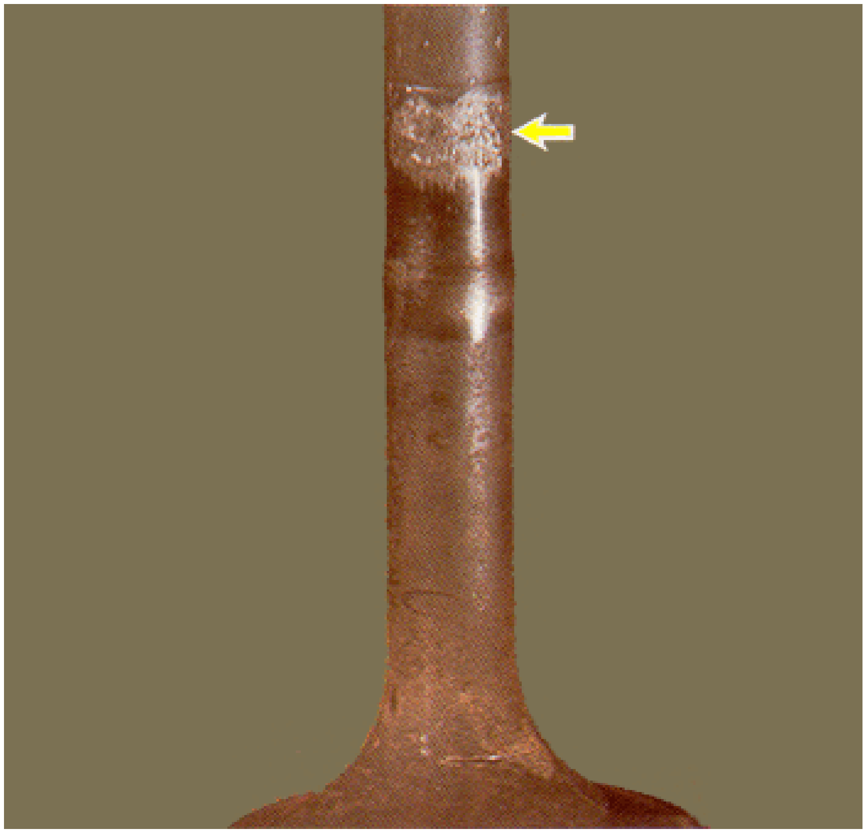
The usual cause of valve stem seizure is deposit collection between the valve stem and guide. Seizure is indirectly caused by the accumulation of deposits-contamination in the oil. More specifically, deposits accumulate from the decomposition of lubricating products into oxidized residue and the normal wastes generated from the combustion process. The progressive buildup of these deposits acts to accelerate bell mouthing of the guide.

Valve stem scuffing and/or seizure can also be caused by lack of lubrication to the valve and valve guide.

Valve seat carbon deposits can create problems if the deposits are excessive. Some lubrication is necessary to prevent extreme wear of the valve seat and the insert in the head. But excessive deposit formation can lead to thick carbon build-up on the valve seat that will then break up and flake out, allowing combustion gas leakage. This hot gas leakage (guttering) allows high temperature across the valve face with cracking and/or melting of the valve.

This type of valve failure can exist in liquid and gas fueled engines. The carbon formation tendency of the oil and the sulfated ash level of the oil affect the carbon formed on the valve seat.

Valve guttering effect caused by excessive deposit formation.



Valve stem scuffing or seizure.

Minimizing the Occurrence of Oil Related Engine Failure

Fuel Sulfur
Oil contamination can take a number of forms, but none is more rapid in its harmful effect than the sulfuric acid that can be produced by high sulfur fuels.

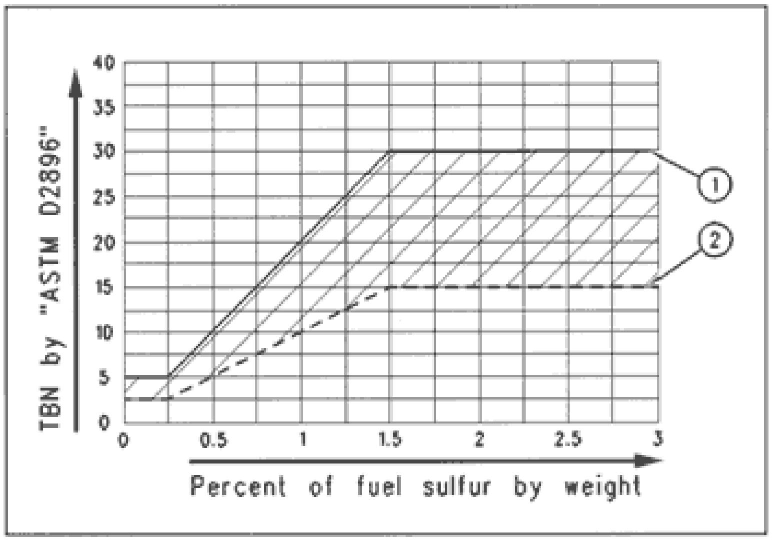
In October 1993, low sulfur fuel was mandated in the United States for on-highway vehicles. In the state of California "ALL" vehicles are required to use low sulfur fuel. Low sulfur fuel was introduced as a means to meet the engine manufacturers' (EMA's) need for emissions control in these applications. There are few or no negative effects of low sulfur fuels.

Coping with the effects of fuel sulfur is not a simple task. Even though the use of proper lubricants and correct intervals reduces the degree of corrosive damage, engine wear will increase significantly when fuels with high sulfur content are used. Not only do these fuels produce acids which chemically attack the engine, causing corrosive wear, but the oils used to negate the acid effects have a higher ash content which increases chances of deposit formation.

Know the fuel sulfur content by periodically asking your supplier or by having the fuel analyzed. Sulfur content can change with each bulk delivery.

Total Base Number (TBN) and Fuel Sulfur Levels for Direct Injection (Dl) Diesel Engines
The Total Base Number (TBN) for an oil depends on the fuel sulfur level. For direct injection engines that use distillate fuel, the minimum TBN of the new oil must be ten times the fuel sulfur level. "STM 02896" defines the TBN. The minimum TBN of the oil is five regardless of fuel sulfur level. Illustration

2 demonstrates the TBN.



1. TBN of new oil
2. Change the oil when the TBN deteriorates to 50 percent of the original TBN.

Use the following guidelines for fuel sulfur levels that exceed 1 .5 percent:

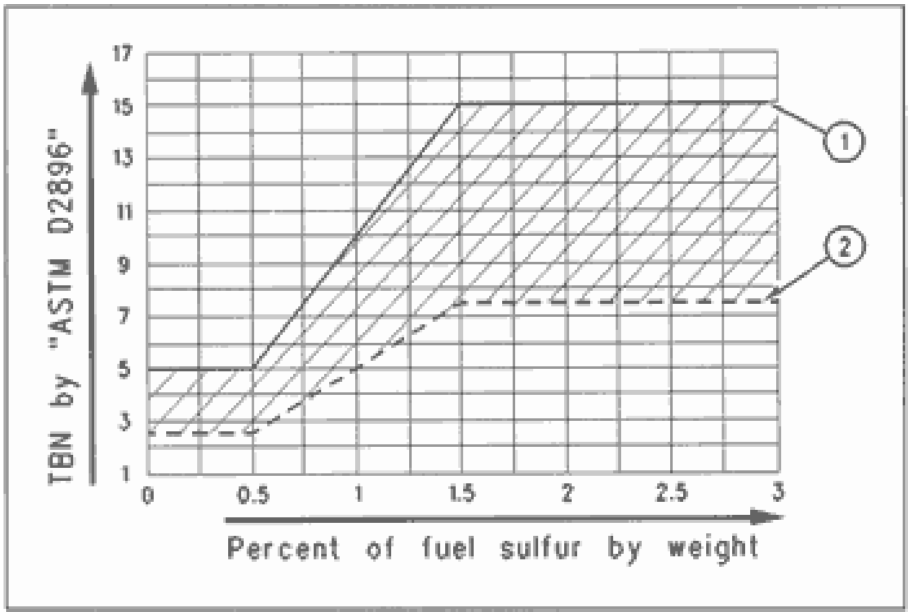
- Choose an oil with the highest TBN that meets one of these classifications: API CH-4, API CG- 4, and API CF-4.
- Reduce the oil change interval, basing the interval on the oil analysis. Ensure that the oil analysis includes the condition of the oil and a wear metal analysis.

Oil with a high TBN can produce excessive piston deposits. These deposits can lead to a loss of control of the oil consumption and to the polishing of the cylinder bore.

NOTICE: Operating Direct Injected (Dl) diesel engines with fuel sulfur levels over 1.0 percent may require shortened oil change intervals in order to help maintain adequate wear protection.

Total Base Number (TBN) and Fuel Sulfur Levels for Precombustion Chamber (PC) Diesel Engines

The TBN for a new oil depends on the fuel sulfur level of the fuel used. The minimum TBN of the oil used in PC engines must be 20 times the fuel sulfur level. The TBN is defined in "ASTM 02896." Regardless of fuel sulfur level, the minimum TBN of new oil is 5. See Illustration 2, below.



1. TBN of new oil
2. Change the oil when the TBN deteriorates to 50 percent of the original TBN.

Whenever the fuel sulfur exceeds 1.5 percent, do the following tasks:

- Choose an oil with the highest TBN that meets one of these classifications: API CF, API CF-4 API CG-4, and API CH-4.
- Reduce the oil change interval, basing the interval on the oil analysis. Ensure that the oil analysis includes the condition of the oil and a wear metal analysis..

NOTICE: Operating PC engines at fuel sulfur levels over 1.0 percent may require shortened oil change intervals to maintain adequate wear protection.

Basic Maintenance of the Lubrication System

Probably the most important step in preventing oil-related failure is to be on the alert as a matter of routine. Specifically, this means being sensitive to the early signs of trouble. One way to do this is with a very basic check for obvious warning signals. Such a check would best be made often and include these 3 key elements:

1. An external check of the engine for any obvious signs of leakage from any compartment.
2. A check of the oil pressure gauge. A change here could indicate anything from a defective oil pump to a stuck pressure relief valve.
3. A check of the oil level gauge. A low oil level could reveal excessive consumption, leakage, or failure of oil lines.

Another important rule of thumb is to adhere to recommended oil and filter change intervals. This is paramount in the fight against oil contamination / degradation, especially with regard to high sulfur fuels.

Summary

In the long run you are directly responsible for your engine's performance. You can lessen the chances of oil-related failure by taking the initiative to protect your engine.

...Select the correct performance category and viscosity of oil for the application.
...Follow the recommended oil and filter change intervals.
...Pay attention to S·O·S SM oil analysis results.