CATERPILLAR®

Special Instruction
Oil and Your Engine{1000}
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Caterpillar Products: All

Introduction

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.

General Information

NOTICE

Every attempt is made to provide accurate, up to date information. By use of this document you agree that Caterpillar Inc. is not responsible for errors or omissions.

The information that is provided are the latest recommendations for Caterpillar engines and for Caterpillar machine compartments. This information supersedes all previous recommendations which have been published for the Caterpillar machines or engines that are covered by this publication. Special lubricants are required for some machine or engine compartments and it will be necessary to continue to use these special products. Refer to the applicable Operation and Maintenance Manual.

NOTICE

Not following the recommendations found in this Special Publication can lead to reduced performance and compartment failure.

Whenever a question arises regarding the machine or engine, this publication, or the Operation and

Maintenance Manual, please consult any Caterpillar dealer for the latest available information.

Safety

Refer to the Operation and Maintenance Manual for your machine for all safety information. Read and understand the basic safety precautions listed in the Safety Section before operating or performing lubrication, maintenance and repair on the machine.

Maintenance

Refer to the Operation and Maintenance Manual for your machine or engine to determine all maintenance requirements.

Maintenance Interval Schedule

Use the Maintenance Interval Schedule in the Operation and Maintenance Manual for your machine or engine to determine servicing intervals. Calendar intervals shown (daily, weekly, monthly, etc.) can be used instead of service hour meter intervals if they provide more convenient servicing schedules and approximate the indicated service hour meter reading. Recommended service should always be performed at the interval that occurs first. Under extremely severe, dusty or wet operating conditions, more frequent lubrication than is specified in the Maintenance Interval Schedule might be necessary.

Extended Engine Oil Drains and Warranty

Failures that result from extended oil drain periods are not Caterpillar factory defects and therefore are not covered by Caterpillar's warranty. In addition, failures that result from not using the recommended oil type are not Caterpillar factory defects and therefore are not covered by Caterpillar's warranty.

Refer to the applicable Operation and Maintenance Manual for standard oil drain periods and to the Maintenance Section, Lubricant Specifications of this publication for engine oil type and viscosity grade recommendations.

To reduce the potential risk of failures associated with extended oil drain periods; it is recommended that oil drain intervals only be extended based on oil analysis, and subsequent engine inspections. Oil analysis alone does not provide an indication of the rate of formation of lacquer, varnish and or carbon on pistons and other engine surfaces. The only accurate way to evaluate specific oil performance in a specific engine and application that utilizes extended oil drain periods is to observe the effects on the engine components. This involves tear-down inspections of engines that have run to their normal overhaul period with extended oil drain intervals. Following this recommendation will help ensure that excessive component wear does not take place in a given application.

NOTICE

Light loads, low hour accumulation, and excessive idling time can contribute to excessive water in the crankcase oil. Corrosive damage, piston deposits and increased oil consumption can also result. If oil analysis is not done or the results are ignored, the potential for corrosive damage and piston deposits increases. Refer to the appropriate Operation and Maintenance Manual for guidance.

Note: Failures that result from extended oil drain periods are not warrantable failures, regardless of use of this recommended procedure. Failures that result from extended engine oil drain periods are considered improper use under the warranty.

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.

Re-refined Basestock Oils

Re-refined basestock oils are acceptable for use in Caterpillar engines **if these oils meet the performance requirements that are specified by Caterpillar.**

Re-refined basestock oils can be used exclusively in finished oil or in a combination with new basestock oils. The US military specifications and the specifications of other heavy equipment manufacturers also allow the use of re-refined basestock oils that meet the same criteria.

The process that is used to make re-refined basestock oil should adequately remove all wear metals that are in the used oil and all additives that are in the used oil. Vacuum distillation and the hydrotreating of the used oil are acceptable processes that are used for producing re-refined base oil.

Note: Filtering is inadequate for the production of high quality re-refined basestock oils from used oil.

Minerals

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 this 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.

Synthetic base oils are acceptable for use in Caterpillar engines and in Caterpillar machines **if these oils meet the performance requirements that are specified by Caterpillar for a particular compartment.** Each compartment has specific lubrication specifications in order to ensure proper lubrication and life of the system.

Synthetic base oils generally perform better than conventional oils in the following two areas:

- Synthetic base oils have improved flow at low temperatures especially in arctic conditions.
- Synthetic base oils have improved oxidation stability especially at high operating temperatures.

Some synthetic base oils have performance characteristics that enhance the service life of the oil. However, Caterpillar does not recommend automatically extending the oil drain interval for any machine compartment for any type of oil, whether synthetic or non-synthetic.

Oil drain intervals for Caterpillar diesel engines can only be adjusted after an oil analysis program that contains the following data:

- Oil condition, oil contamination, and wear metal analysis (Caterpillar S·O·S[SM] Services Oil Analysis)
- Trend analysis
- Fuel consumption
- Oil consumption

Refer to the Extended Engine Oil Drains and Warranty article in the forward of this special publication.

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 antioxidants 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; styrenebased 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.

Aftermarket Oil Additives

Caterpillar does not recommend the use of aftermarket additives in oil. It is not necessary to use aftermarket additives in order to achieve the maximum service life or rated performance of the machine or engine. Fully formulated, finished oils consist of base oils and of commercial additive packages. These additive packages are blended into the base oils at precise percentages in order to help provide finished oils with performance characteristics that meet industry standards.

There are no industry standard tests that evaluate the performance or the compatibility of aftermarket additives in finished oil. Aftermarket additives may not be compatible with the finished oil's additive package, which could lower the performance of the finished oil. The aftermarket additive could fail to mix with the finished oil. This could produce sludge. Caterpillar discourages the use of aftermarket additives in finished oils.

To achieve the best performance from Caterpillar machines or engines, conform to the following guidelines:

- Select the proper Caterpillar oil or select commercial oil that meets the specifications designated by Caterpillar for the compartment.
- See the appropriate Lubricant Viscosities for Ambient Temperatures table in this publication in order to find the correct oil viscosity grade.
- At the specified interval, service the engine or service the other machine compartments. Use appropriate new oil and install an appropriate new oil filter.
- Perform maintenance at the intervals that are specified in the Operation and Maintenance Manual, Maintenance Interval Schedule.

Total Base Number

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 sulfuric 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 oil viscosity grades.

Table 1

SAE Viscosity Grades For Engine Oils [1] - SAE J300 Dec 99					
SAE Viscosity Grade	**Low Temperature Viscosities**		**High Temperature Viscosities**		
	Cranking [2] (cP [3]) Max at Temp °C	**Pumping [4] (cP) max with no yield stress at temp °C**	**Low Shear Rate Kinematic [5] (cSt) at 100° C**		**High Shear [6]**
			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	Less than 9.3	2.6
30			9.3	Less than 12.5	2.9
40			12.5	Less than 16.3	Less than 2.9 (0W-40, 5W-40, 10W-40 grades)
40			12.5	Less than 16.3	3.7 (15W-40, 20W-40, 25W-40, 40 grades)
50			16.3	Less than 21.9	3.7
60			21.9	Less than 26.1	3.7

(1) All values are critical specifications as defined by ASTM D 3244 (see J300 text)

(2) ASTM D 5293

(3) cP = 1mPa s: 1 cSt = 1mm2 s

(4) ASTM D 4684: The presence of any yield stress detectable by this method constitutes a failure regardless of viscosity.

(5) ASTM D 445

(6) ASTM D 4683, ASTM D 4741, CEC-L-36-A-90

Note: The new standard carries a revision date of December 1999. Mandatory compliance with the new Cranking limits begin June 2001.

API Engine Oil Classifications

The diesel and gasoline 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, API SL and API SM.

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 CJ-4, API CI-4 CI-4PLUS, API CH-4 and API CF. API CF-4 has been obsolete since June of 2008 and API CG-4 is in the process of becoming obsolete. It is expected that the last CG-4 license will expire by June of 2009.

API-CJ-4 – Introduced in 2006 for Heavy Duty Diesel Engine Service

API CJ-4 was developed for high-speed, four-stroke engines designed to meet 2007 model year on-highway exhaust emission standards. API CJ-4 oils that also satisfy Cat ECF-3 are strongly recommended for use in all applications and are compatible with off-highway applications. Because API CJ-4 oils were developed for use with Ultra Low Sulfur Diesel (ULSD) fuel of 15 ppm (0.0015% by weight) sulfur or less, the use of fuels with higher sulfur level may impact the oil drain interval and S.O.S oil analysis is recommended. When API CJ-4 oils are used with diesel fuels of sulfur levels greater than 500 ppm (0.05%), S.O.S oil analysis is very strongly recommended. Note that the use of fuels with greater than 15 ppm (0.0015%) sulfur fuel in aftertreatment equipped engines is can negatively impact exhaust aftertreatment system durability and shorten the mandated cleaning service intervals.

API CJ-4 oil is the first oil category developed with chemical limits. API CJ-4 oils are formulated with a maximum of 1%sulfated ash, a maximum of 0.4% sulfur and a maximum of 0.12% phosphorous. For this reason, API CJ-4 oils are effective at sustaining emission control system durability where particulate filters and other advanced aftertreatment systems are used.

API CJ-4 oils provide optimum protection for control of catalyst poisoning, particulate filter blocking, engine wear, piston deposits, low and high temperature stability, soot handling properties, oxidative thickening, foaming, and viscosity loss due to shear. API CJ-4 oils exceed the performance criteria of API CI-4 CI-4 PLUS, CH-4, and CF service categories and in most applications can effectively lubricate engines calling for those API Service Categories.

API CI-4 Introduced in 2002 for Heavy Duty Diesel Engine Service

API CI-4 oils were developed for high-speed, fourstroke cycle diesel engines designed to meet 2004 exhaust emission standards. API CI-4PLUS was developed for high-speed four-stroke cycle diesel engines, including engines using EGR (Exhaust Gas Recirculation). Hence this oil is designed to disperse large percentage of soot that can be generated by the EGR technology, while fully compatible with non-EGR engines. API CI-4 CI-4PLUS oils that also satisfy Cat ECF-2 are strongly recommended for use in all applications that do not utilize a diesel particular filter (DPF). These oils are also compatible with off-highway applications. API CI-4 CI-4PLUS oils are compounded for use in all applications with diesel fuels of sulfur content up to 500 ppm (0.05% by weight). For applications with fuel sulfur level greater than 500 ppm (0.05%), S.O.S oil analysis is strongly recommended to determine optimal oil drain interval.

API CI-4 CI-4PLUS oils that also satisfy Cat ECF-2 specification provide optimum protection for control of corrosive wear tendencies, low and high temperature stability, soot handling properties, piston deposit control, valvetrain wear, oxidative thickening, foaming and viscosity loss due to shear. API CI-4 CI-4PLUS oils exceed the performance criteria of API CH-4, and CF Service Categories.

API CH-4 oils – Introduced in 998 for Heavy Duty Diesel Engine Service.

API CH-4 oils were developed in order to meet the requirements of high –speed four-stroke diesel engines with pre-2002 emissions requirements. API CH-4 oils the also satisfy Caterpillar ECF-1-a specification are acceptable for use in Caterpillar engines that do not utilize aftertreament devices. API CH-4 oils are acceptable for use in older diesel engines and in diesel engines that use high sulfur diesel fuel. API CH-4 oils will generally exceed the performance of prior API categories, most of which are now obsolete or in the process of becoming obsolete, in the following criteria: deposits on pistons, control of oil consumption, wear of piston rings, valve train wear, viscosity control, soot dispersion and corrosion.

It is important to note that the more advanced the API category, the more performance engine and bench tests the category requires. API CJ-4 requires 15 engine and bench tests, including the demanding multi-cylinder Cat C13 engine test and three new full-scale engine tests. In comparison, API CI-4 requires 14 engine and bench tests and API CH-4 require 12 engine and bench tests. Some of the engine tests common to multiple categories may have more strict limits in the more advanced oils. This process ensures that the newer engine oil categories offer superior protection of the engines compared to the preceding ones and are backwards compatible.

Customers need to know that Caterpillar engine oil requirements are per Caterpillar ECF specifications, which may have more additional requirements to API categories. Cat ECF specifications are discussed in detail later in this section.

API CG-4 oils are no longer accepted in Caterpillar engines. This oil category is not robust and does not meet the minimum requirements to protect Cat engines.

Note: Do not use single grade API CF oils or multigrade API CF oils in Caterpillar Direct Injection (DI) 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 SOSSM 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.

Engine Oil - Engine Crankcase Fluid Recommendations for all Caterpillar 3500 Series, C175 Series, and Smaller Direct Injection (DI) Engines

Exceptions to these recommendations are 3116 and 3126 Marine Engines with Mechanical Unit Injection (MUI).

Cat Diesel Engine Oils

Cat oils have been developed and tested in order to provide the full performance and service life that has been designed and built into Cat engines. Cat oils are formulated with high quality basestocks and with optimal amounts and composition additives. Cat oils are currently used to fill diesel engines at the factory. These oils are offered by Cat dealers for continued use when the engine oil is changed and for aftermarket service of the engines. Consult your Cat dealer for more information on these oils.

Due to the additional full-scale proprietary engine testing required of Cat DEO-ULS and Cat DEO,, and due to significant variations in the quality and in the performance of commercially available oils, Caterpillar makes the following recommendations:

- Cat DEO-ULS (Diesel Engine Oil - Ultra Low Sulfur) (15W-40, 10W-30 and 5W-40)

- Cat DEO (Diesel Engine Oil) (15W-40, 10W-30, 5W-40 and 0W-30)

Note: Cat DEO-ULS and Cat DEO multigrade oils are the preferred oils for use in ALL Cat diesel engines. More information can be obtained from SEBU documents and from Cat dealers. Commercial alternative diesel engine oils are, as a group, second choice oils.

Cat DEO-ULS multigrade and Cat DEO multigrade oils are formulated with the correct amounts and composition of additives including detergents, dispersants, and alkalinity in order to provide superior performance in Cat diesel engines where recommended for use.

Cat DEO-ULS and Cat DEO multigrade oils are available in various viscosity grades that include SAE 10W-30 and SAE 15W-40. Multigrade oils provide the correct viscosity for a broad range of operating temperatures.

Note: Do not use single grade oils in Caterpillar 3500 Series, C175 Series and smaller Direct Injection (DI) diesel engines.

NOTICE

Oils that have more than 1% total sulfated ash should not be used in aftertreatment device equipped engines.

In order to achieve expected ash service intervals, performance, and life, aftertreatment device equipped diesel engines require the use of Cat DEO-ULS or oils meeting the Cat ECF-3 specification and the API CJ-4 oil category. Oils that meet the Cat ECF-2 specification and that have a maximum sulfated ash level of 1% are also acceptable for use in most aftertreatment-equipped engines. Use of oils with more than 1% total sulfated ash in aftertreatment device equipped engines will cause the need for more frequent ash service intervals, and or cause loss of performance. Refer to your engine specific Operation and Maintenance Manual, and refer to your aftertreatment device documentation for additional guidance.

Cat DEO-ULS multigrade and Cat DEO multigrade oils can be used in other manufacturer's diesel engines and in gasoline engines. See the engine manufacturer's literature for the recommended categories specifications. Compare the categories specifications to the specifications of Cat DEO-ULS multigrade and Cat DEO multigrade oils. The current industry standards for Cat DEO-ULS multigrade and Cat DEO multigrade oils are listed on the product labels and on the datasheets for the product.

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

Cat DEO-ULS and Cat DEO pass additional proprietary accelerated multi-cylinder engine tests and bench tests that are above and beyond the testing by the various API categories they meet and the various Cat ECF specifications. The additional tests include the following: sticking of the piston ring, oil control tests, wear tests and soot tests. Proprietary tests help ensure that Cat multigrade oil provides superior performance in Cat diesel engines. In addition, Cat multigrade oils exceed many of the performance requirements of other manufacturers of diesel engines. Therefore, these oil are excellent choices for many mixed fleets. True high performance oil is produced by using a combination of the following factors: industry standard tests, proprietary tests, field tests and prior experience with similar formulations. The design and the development of Caterpillar lubricants that are both high performance and high quality are based on these factors.

Commercial Oils

Caterpillar developed the Engine Crankcase Fluid (ECF) specifications to ensure the availability of high performance commercial diesel engine oils in order to provide satisfactory life and performance in Cat diesel engines where recommended for use.

There are three current Cat ECF specifications:

- Cat ECF-3
- Cat ECF-2
- Cat ECF-1-a

Each higher specification provides increased performance over lower Cat specification. For example, Cat ECF-3 provides higher performance than Cat ECF-2 and much higher performance than Cat ECF-1-a.

Note: Non-Caterpillar commercial oils are, as a group, second choice oils. Within this grouping of second choice oils there are tiered levels of performance.

NOTICE

Caterpillar does not warrant the quality or performance of non-Caterpillar fluids.

Cat DEO-ULS multigrade exceeds the requirements of the Cat ECF-1-a, Cat ECF-2, and Cat ECF-3 specifications. Cat DEO-ULS multigrade exceeds the performance requirements for the following API oil categories: API CJ-4, API CI-4 CI-4 PLUS, API CH-4, and API CF.

Cat DEO multigrade exceeds the requirements of the following Cat Engine Crankcase Fluid (ECF) specifications: Cat ECF-1-a and Cat ECF-2.Cat DEO multigrade exceeds the performance requirements for the following American Petroleum Institute (API) oil categories: API CI-4 CI-4 PLUS, API CH-4, and API CF.

Note: API CF-4 is obsolete and API CG-4 will be obsolete in June of 2009. Oils claiming the performance requirements of these two oil categories are inferior to the current API oils and are not acceptable in Cat engines.

Note: The availability of Cat DEO multigrade and DEO-ULS multigrade exceeding the noted requirements will vary by region.

Note: Cat DEO-ULS and DEO are required to pass additional proprietary full-scale diesel engine and bench testing that is above and beyond the testing required by the various Cat ECF specifications and by the various API oil categories that they also meet. This additional proprietary testing helps ensure that Cat multigrade diesel engine oils, when used as recommended, provide superior performance in Cat diesel engines. If Cat DEO multigrade or DEO-ULS multigrade oils are not used, as a second choice, use only commercial oils that meet the following specifications:

- When the recommended and preferred Cat diesel engine oils are not used, commercial oils that meet the requirements of the Cat ECF-1-a, Cat ECF-2, and or the Cat ECF-3 specification are acceptable for use in Cat diesel engines per the requirements of the Operating and Maintenance Manual of the engine. API category oils that have not met the requirements of at least one Cat ECF specification may cause reduced engine life. Note that in order to achieve the maximum expected engine performance and life, some engines engine applications will require the use of higher performance oils such as those meeting Cat ECF-3 versus meeting Cat ECF-2 or Cat ECF-1-a.

- When the recommended and preferred Cat diesel engine oils are not used, commercial oils that meet the requirements of the Cat ECF-3 specification are acceptable for use in Cat diesel engines per the requirements of the Operating and Maintenance Manual of the engine.. After Cat DEO-ULS and Cat DEO, commercial oils that meet the Cat ECF-3 specification are preferred oils, when compared to commercial diesel engine oils that do not meet the Cat ECF-3 specification for use in Cat diesel engines per the requirements of the Operating and Maintenance Manual of the engine. Note that in order to achieve the maximum expected engine performance and life, some engines engine applications will require the use of higher performance oils such as those meeting Cat ECF-3 versus meeting Cat ECF-2 or Cat ECF- 1-a.

Oils that meet the API CJ-4 oil category requirements are Cat ECF-3 specification compliant.

Severe Applications Require the Use of Higher Performing Diesel Engine Oils

In order to help ensure the maximum expected compartment performance and life, severe duty applications such as those operating at greater than 75% load factor, operating in high humidity, operating with fuel sulfur levels that are above 0.1% (1000 ppm), etc., require the use of higher performing fluids as described in this Special Publication, versus using fluids that meet the minimum performance levels that may be allowed for typical applications.(ex: Where fluids meeting either Cat ECF-1-a, Cat ECF-2 or Cat ECF-3 are offered as an option in typical applications, in order to help ensure the maximum expected engine compartment performance and life, oil meeting the Cat ECF-3 specification must be used.)

Note: There are additional oil considerations that are related to fuel sulfur levels. Refer to the various Total Base Number (TBN) and Fuel Sulfur Levels topics in this Special Publication. Also refer to the Diesel Fuel Sulfur topic in this Special Publication.

NOTICE

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

In order to make the proper diesel engine oil viscosity grade choice, refer to the Lubricant Viscosities for Ambient Temperatures for DI Diesel Engines table in this Special Publication.

NOTICE

Oils that have not met the requirements of at least one Cat ECF specification may cause reduced engine life.

NOTICE

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

Total Base Number (TBN) and Fuel Sulfur Levels for Direct Injection (DI) Diesel Engines

The use of Cat SOSSM Services oil analysis is strongly recommended for determining oil life.

Note: The following information concerning oil life relative to used oil TBN level is provided for general information only, and is not the recommended method for determining oil life. **If the one half of new oil TBN guideline that is stated below is used for determining oil life it must only be used in conjunction with a complete SOS^{SM} Services oil analysis program.**

Note: TBN is also commonly referred to as Base Number (BN).

The minimum required Total Base Number (TBN) for oil depends on the fuel sulfur level. For direct injection engines that use distillate fuel, the minimum new oil TBN must be 10 times the fuel sulfur level. The TBN for new oil is typically determined by the ASTM D2896 procedure.

Note: The minimum TBN of the new oil is 5 regardless of the fuel sulfur level. Reaching one half of new oil TBN is one of the condemning factors for diesel engine oil, but, in order to help provide the best protection for your engine, Cat SOS^{SM} Services oil analysis is the preferred method of determining oil life. For best results when determining oil life using the one half new oil TBN method, determine the new and used oil TBN using both the ASTM D2896 and the ASTM D4739 test methods. Change the oil when reaching one half of new oil TBN with either respective TBN test method using the results from which ever respective test method shows reaching one half of new oil TBN first.

For example, new oil with a TBN of 10 by ASTM D2896 should be changed when, during use, the TBN deteriorates to 5 as determined by the ASTM D2896 test method, and new oil with a TBN of 10 by ASTM D4739 should be changed when, during use, the TBN deteriorates to 5 as determined by the ASTM D4739 test method. Use the results from which ever respective test method reaches one half of new oil TBN first.

Excessive piston deposits can be produced by oil with a high TBN and or high ash. These deposits can lead to a loss of control of the oil consumption and to the polishing of the cylinder bore.

There are many factors that contribute to rapid TBN depletion, a not all inclusive list follows:

- High sulfur fuel (The more fuel sulfur, the more rapid the TBN depletion.)
- Faulty engine coolant regulators
- Light loads
- Short operation cycles
- Excessive idling
- Operating in applications were normal operating temperature is seldom reached
- High humidity (allowing excessive condensation)

Note that bullets 2 through 7 directly above all can contribute to excessive water in the crankcase oil. The water combines with available sulfur to form sulfuric acid, neutralizing this and other acids that are formed contribute to rapid TBN depletion.

NOTICE

Depending on application severity and localized environmental conditions, and also depending on maintenance practices, operating Direct Injection (DI) diesel engines and operating PC (Precombustion Chamber) diesel engines on fuel with sulfur levels over 0.1 percent (1000 ppm) may require significantly shortened oil change intervals in order to help maintain adequate wear protection. Refer to this Special Publication, Fuel Specifications section, Diesel Fuel Sulfur topic for additional information.

Note: For PC (Precombustion Chamber) diesel engines, which are mainly 1990 and older engines, the minimum new oil TBN must be 20 times the fuel sulfur level. The diesel engine oil types, specifications, and viscosity grades recommendations provided for DI diesel engines in this Special Publication are also applicable to PC diesel engines. For additional fluids information related to PC diesel engines, refer to this Special Publication, Engine Oil for Precombustion Chamber (PC) Diesel Engines (Engine Crankcase Fluid Recommendations for All Series 3500 Series and Smaller PC Diesel Engines) article.

Note: DO NOT USE ONLY THIS SPECIAL PUBLICATION AS A BASIS FOR DETERMINING OIL DRAIN INTERVALS.

This Special Publication does not address recommended oil drain intervals, but rather provides guidance that should be used in conjunction with your specific engine machine Operation and Maintenance Manuals in determining acceptable oil drain intervals. Consult your engine machine Operation and Maintenance Manuals, and consult Caterpillar dealers for additional guidance, including but not limited to guidance on establishing optimized and or acceptable oil drain intervals.

Note: The use of Cat S·O·S^{SM} Services oil analysis helps environmental sustainability as it is the best way to optimize oil life, and will help engines reach their expected life. Consult with your Caterpillar dealer regarding the testing required to establish a safe, optimized oil drain interval.

Standard oil drain intervals as published in engine specific Operation and Maintenance Manuals are for typical applications:

- Using recommended oils
- Using good fuel
- Using industry standard good maintenance practices
- Following maintenance intervals as published in engine specific Operation and Maintenance Manuals

More severe applications may require shortened oil drain intervals, while less severe applications may allow for longer than standard oil drain intervals. High load factors (above 75%), particularly in conjunction with high sulfur fuels, can contribute significantly to reducing oil drain intervals below standard oil drain intervals.

Consult with your Caterpillar dealer regarding the testing that is required in establishing oil drain intervals that are optimized for your application.

In order to help protect your engine, and in order to help optimize oil drain intervals for engine specific applications and duty cycles, Cat S·O·S^{SM} Services oil analysis is:

- Recommended as a matter of course
- Very strongly recommended in order to determine oil drain intervals when operating on fuel with sulfur levels between 0.05% (500 ppm) and 0.5% (5000 ppm)
- Required in order to determine oil drain intervals when operating on fuel with sulfur levels that are above 0.5% (5000 ppm)

Note: Engine operating conditions play a key role in determining the effect that fuel sulfur will have on engine deposits and on engine wear. Consult your Caterpillar dealer for guidance when fuel sulfur levels are above 0.1% (1000 ppm).

Selecting the Viscosity

Ambient temperature is the temperature of the air in the immediate vicinity of the engine. This may differ due to the engine application from the generic ambient temperature for a geographic region. When selecting the proper oil viscosity for use, review both the regional ambient temperature and the potential ambient temperature for a given engine application. Generally, use the higher temperature as the criterion for the selection of the oil viscosity. Generally, use the highest oil viscosity that is allowed for the ambient temperature when you start the engine. In arctic applications, the preferred methods are to use a heated enclosure, or properly sized engine heaters and a higher viscosity grade oil. Thermostatically controlled heaters that circulate the oil are preferred.

The proper oil viscosity grade is determined by the minimum ambient air temperature (the air in the immediate vicinity of the engine). This is the temperature when the engine is started and while the engine is operated. In order to determine the proper oil viscosity grade, refer to the Min column in the table. This information reflects the coldest ambient temperature condition for starting a cold engine and for operating a cold engine. Refer to the Max column in the table in order to select the oil viscosity grade for operating the engine at the highest temperature that is anticipated. Use the highest oil viscosity that is allowed for the ambient temperature when you start the engine.

Engines that are operated continuously and or are heavily loaded should use oils that have the higher oil viscosity. The oils that have the higher oil viscosity will maintain the highest possible oil film thickness. Consult your dealer if additional information is needed.

Note: SAE 0W and SAE 5W oils are generally not recommended for use in engines that are operated continuously and or are heavily loaded. The oils that have the higher oil viscosity will maintain the highest possible oil film thickness. Consult your Caterpillar dealer if additional information is needed.

NOTICE

Proper oil viscosity AND oil type (category specification) are required to maximize engine performance and life. Do NOT use only oil viscosity, or only oil type to determine the engine oil selection. Using only the oil viscosity or only the oil type to determine the engine oil selection can lead to reduced performance and engine failure.

NOTICE

The footnotes are an integral part of the Lubricant Viscosities for Ambient Temperatures tables - read all footnotes!

NOTICE

In colder ambient conditions an engine warm-up procedure and or supplemental engine fluid compartment heat may be required. Engine specific warm-up procedures can typically be found in the Operation and Maintenance Manual for the engine.

NOTICE

Not following the recommendations found in the Lubricant Viscosities for Ambient Temperatures Tables and associated footnotes can lead to reduced performance and engine failure.

NOTICE

Do NOT use only the oil viscosities when determining the recommended oil for an engine compartment. The oil type (category specification) MUST also be used.

Note: Different brand oils may use different additive packages to meet the various engine performance category specification requirements. For the best results, do not mix oil brands.

Note: The availability of the various Caterpillar oils will vary by region.

Illustration 1 g02142441

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

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

Refer to Table 2 (minimum temperature) in order to determine the required oil viscosity for starting a cold engine.

Refer to Table 2 (maximum temperature) in order to select the oil viscosity for engine operation at the highest ambient temperature that is anticipated.

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

If ambient temperature conditions at engine start-up require the use of multigrade SAE 0W oil, SAE 0W-40 viscosity grade is generally preferred over SAE 0W-30.

Note: SAE 10W-30 is the preferred viscosity grade for the following diesel engines when the ambient temperature is above -18 °C (0 °F), and below 40 °C (104 °F).

- C7
- C-9
- C9
- 3116
- 3126

Table 2

Lubricant Viscosities for Ambient Temperature for DI Diesel Engines (1) (2)		
Caterpillar DEO Multigrade API CH-4, API CG-4 and API CF-4 Viscosity Grade	Ambient Temperature	
	Minimum	Maximum

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)	50 °C (122 °F)
SAE 10W30 (3)	-18 °C (0 °F)	40 °C (104 °F)
SAE 10W40	-18 °C (0 °F)	50 °C (122 °F)
SAE 15W40	-9.5 °C (15 °F)	50 °C (122 °F)

(1) Refer to this Special Publication, Engine Oil article for rcommendations of diesel engine oil type.

(2) Supplemental heat is recommended for cold-soaked starts below the minimum ambient temperature. Supplemental heat may be required for cold-soaked starts that are above the minimum temperature that is stated, depending on the parasitic load and other factors. Cold-soaked starts occur when the engine has not been operated for a period of time, allowing the oil to become more viscous due to cooler ambient temperatures.

(3) SAE10W-30 is the preferred viscosity grade for the 3116, 3126, C7, C-9 and C9 diesel engines when the ambient temperature is between -18 °C (0 °F) and 40 °C (104 °F).

Refer to Table 2 and associated footnotes for guidance on selecting the proper oil viscosity grade for various ambient temperatures.

Note: C175 Series diesel engines require the use of multigrade SAE 40 oil. IE: SAE 0W-40, SAE 5W-40, SAE 10W-40, or SAE 15W-40. In ambient temperatures of -9.5 °C (15 °F) or above, SAE 15W-40 is the preferred oil viscosity grade. Refer to table 1 and associated footnotes for guidance on selecting the proper oil viscosity grade for various ambient temperatures.

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 any one 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), cosponsored 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.

Illustration 2 g02142675

Cold Weather Lubricants

NOTICE

Recommended engine warm-up procedure must be followed. Refer to the engine Operation and Maintenance Manual. Also refer to the relevant Lubricant Viscosities for Ambient Temperatures table footnote in this Special Publication.

NOTICE

Excessive engine idling time can contribute to excessive water in the crankcase oil, causing corrosion, sludge, and other problems. Excessive engine idling time can also lead to injector fouling, piston and combustion chamber deposits, corrosive damage, and increased oil consumption.

For proper selection of oil type, refer to the applicable Engine Oil article in this Special Publication.

For the proper selection of oil viscosity grade, refer to the Lubricant Viscosities for Ambient Temperatures tables in this Special Publication. Also, refer to this Special Publication, Lubricant Viscosities article.

Before attempting to start the engine, make sure that the oil in the engine is fluid enough to flow. Check the oil by removing the dipstick. If the oil will drip from the dipstick, then the oil should be fluid enough to allow the engine to start. Do not use oil that has been diluted with kerosene. Kerosene will evaporate in the engine. This will cause the oil to thicken. Kerosene will cause swelling and softening of the silicone seals. Kerosene will dilute the oil's additives. Dilution of the oil's additives will reduce the oil's performance, and reduce the engine protection that the additives provide.

If the viscosity of the oil is changed for colder weather, also change the filter element. If the filter is not changed, the filter element and the filter housing can become a solid mass. After the oil is changed, operate the engine to circulate the thinner oil.

When you start a cold-soaked engine or when you operate an engine in ambient temperatures that are below−18°C (0°F) use base oils that can flow in low temperatures. These multigrade oils have lubricant viscosity grade of SAE 0W or of SAE 5W. An example of viscosity grade is SAE 5W-40.

When you start a cold-soaked engine or when you operate an engine in ambient temperatures that are below −30°C (−22°F), use a synthetic base stock multigrade oil. The oil should have a lubricant viscosity grade of SAE 0W or SAE 5W. Use an oil with a pour point that is lower than −40°C (−40°F).

Note: Use the highest oil viscosity grade that is allowed for the ambient temperature when you start the engine. If a different oil viscosity grade is specified in the table for Lubricant Viscosities for Ambient Temperatures, use the viscosity grade that is specified in the table. In arctic applications, the preferred method of lubrication is to use an engine compartment heater that is properly sized and to use oil that is a higher viscosity grade. Refer to the Lubricant Viscosities article in this Special Publication for further details.

Note: Cold-soaked starts occur when the engine has not been operated for a period of time, allowing the oil to become more viscous due to cooler ambient temperatures. Supplemental heat is recommended for cold-soaked starts that are below the minimum ambient temperatures listed in the Lubricant Viscosities for Ambient Temperatures tables. Supplemental heat may be required for cold-soaked starts that are above the minimum temperature that is stated, depending on the parasitic load and other factors.

NOTICE

Engines that use fluid or pan heaters, or heated enclosures, or are kept running under load, etc. can, and generally should use higher viscosity oil. The Lubricant Viscosities for Ambient Temperatures tables (Maintenance Section) Minimum viscosity for ambient temperature recommendations are for cold-soaked conditions. Use the highest viscosity oil that is allowed for the ambient temperature when you start the engine - BUT, under Continuous Usage (Multiple Shifts Day), and or when using fluid or pan heaters, etc., use a higher viscosity oil, NOT the oil with the minimum recommended viscosity for coldsoaked starting conditions. The higher viscosity oil will maintain the highest possible oil film thickness. Refer to the Lubricant Viscosities for Ambient Temperatures tables and the table footnotes for exceptions.

Example: The oil viscosity recommended for use in Caterpillar diesel engines for cold-soaked starts at −40 °C (−40 °F) is multigrade oil of the SAE 0W viscosity grade (SAE 0W-30, etc.). If the diesel engine is run continuously, SAE 15W-40 viscosity grade diesel engine oil can be used - and is generally the preferred oil viscosity in this situation.

NOTICE

If ambient conditions warrant, a higher viscosity oil of the recommended specification category for a given compartment may need to be installed in order to provide adequate film thickness.

NOTICE

Recommended engine warm-up procedure must be followed. Refer to the Operation and Maintenance Manual.

Cleanliness Oil Filtering

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.

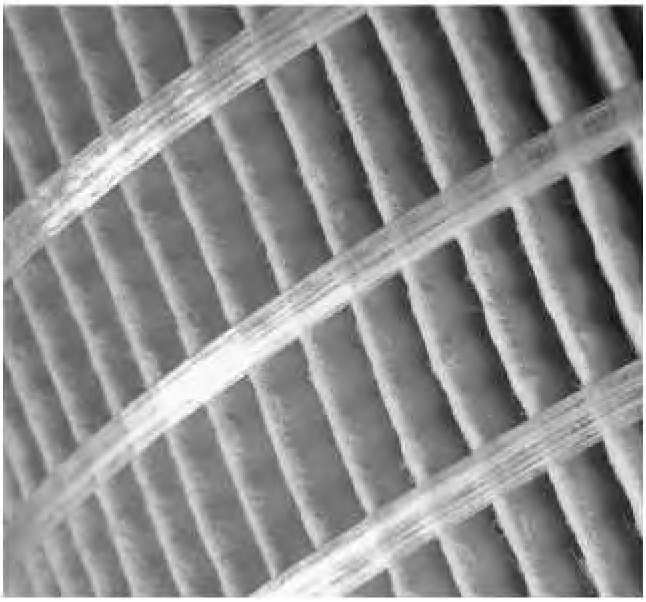

Illustration 3 g02142677

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

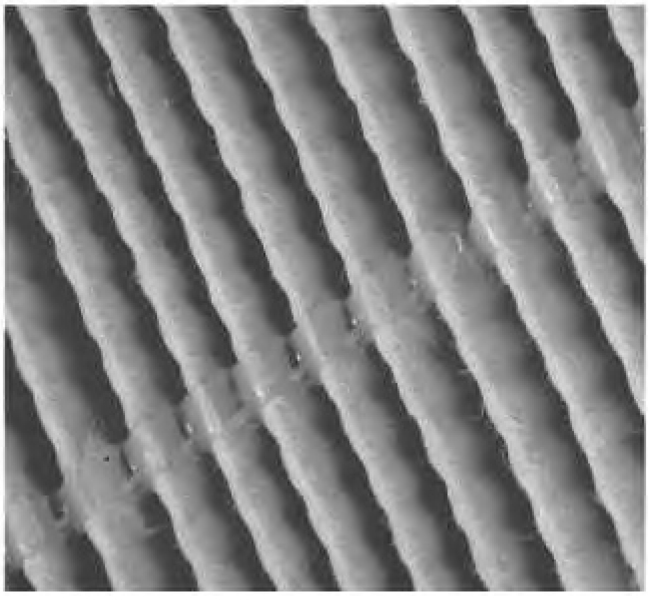

Illustration 4 g02142778

Proprietary Media designed to maximize engine life.

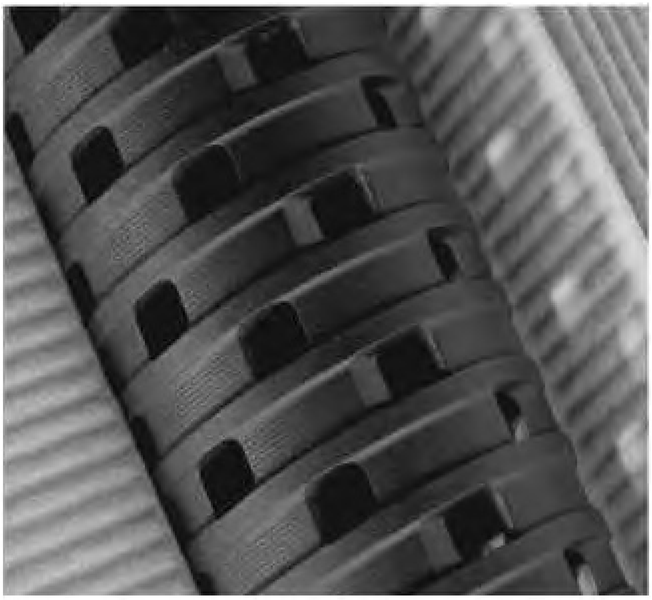

Illustration 5 g02142779

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

Illustration 6 g02142783

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

Contamination & Degradation

Illustration 7 g02142785

Taking an oil sample.

Illustration 8 g02142787

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

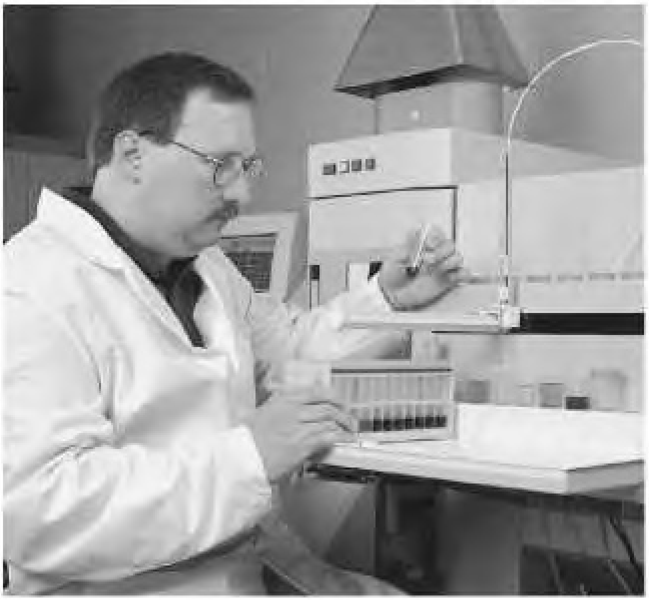

Illustration 9 g02142793

Analyzing an oil sample using an inductively coupled plasma spectrophotometer.

Illustration 10 g02142795

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

Oil Maintenance

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.

S·O·S^{SM} Services Oil Analysis

NOTICE

These recommendations are subject to change without prior notice. Consult your local Caterpillar dealer for the most up to date recommendations.

Caterpillar has developed a maintenance management tool that evaluates oil degradation and detects the early signs of wear on internal components. The Caterpillar tool for oil analysis is called S·O·S^{SM} oil analysis and the tool is part of the S·O·S^{SM} Services program. S·O·S^{SM} oil analysis divides oil analysis into four categories:

- Component wear rate
- Oil condition
- Oil contamination
- Oil identification

Component Wear Rate analysis evaluates the wear that is taking place inside the lubricated compartment. The S·O·S^{SM} Services analyst uses the results of elemental analysis and particle count tests to evaluate the wear. Trend analysis and proprietary wear tables are then used to determine if wear rates are normal or abnormal.

Oil Condition analysis is used to determine if the oil has degraded. Tests are done to look at the oxidation, sulfation, and viscosity of the oil. The S·O·S^{SM} Services analyst uses established guidelines or trend analysis to determine if the oil has reached the end of its useful life.

Oil Contamination tests are performed to determine if anything harmful has entered the oil. This analysis relies on the results from the following tests: elemental analysis, soot, particle count, fuel dilution, water, and glycol. The S·O·S^{SM} Services program has guidelines for the level of contamination that are allowed in Cat engines.

Oil Identification is another very important part of the S·O·S^{SM} oil analysis program. The wrong oil in an engine can severely damage major components. The S·O·S^{SM} Services analyst uses elemental analysis and viscosity results to identify key characteristics of the oils.

These four types of analysis are used to monitor the condition of equipment and help identify potential problems. A properly administered S·O·S^{SM} Services oil analysis program will reduce repair costs and the program will lessen the impact of downtime.

The S·O·S^{SM} oil analysis program uses a wide range of tests to determine the condition of the oil and the condition of the lubricated compartment.

Guidelines that are based on experience and a correlation to failures have been established for these tests. See the following chart for the guidelines. Exceeding one or more of these guidelines could indicate serious fluid degradation or a pending component failure. A trained person at your Caterpillar dealership should make the final analysis.

Note: Cooling system problems will also reduce the life of engines. S·O·S^{SM} coolant analysis together with S·O·S^{SM} oil analysis provide a complete and accurate method for monitoring the health of all engine systems. Refer to the S·O·S^{SM} Services coolant analysis information in this Special Publication. A properly administered S·O·S^{SM} Services program will reduce repair costs and lessen the impact of downtime.

Consult your Caterpillar dealer for complete information and assistance about the S·O·S^{SM} oil analysis program.

Obtaining S·O·S^{SM} Oil Samples

Before you obtain an S·O·S^{SM} oil sample, operate the engine until the oil is warm and the oil is well circulated. Then obtain the S·O·S^{SM} oil sample.

In order to obtain a good oil sample, do not take the oil sample from the drain stream. The drain stream method can allow a stream of dirty oil from the bottom of the compartment to contaminate the sample. Likewise, never dip an oil sample from an oil container or pour a sample from a used filter.

There are two acceptable ways to obtain S·O·S^{SM} oil samples. The following methods are listed in the order that is preferred:

- Use an in-line sampling valve on the pressurized oil manifold.
- Use a sampling gun (vacuum pump) that is inserted into the sump.

Use of the in-line sampling valve is the preferred method. This method provides samples that are less likely to be contaminated.

In order to obtain an oil sample from the engine, it may be necessary to increase the engine's speed. Normally, the oil sample is taken at low idle. If the flow rate is too low, increase engine speed to high idle in order to obtain the oil sample.

NOTICE

Always use a separate vacuum pump for oil sampling, and use a separate pump for coolant sampling. Using the same pump for both types of samples may contaminate the samples that are being drawn. This contaminate may cause a false analysis and an incorrect interpretation that could lead to concerns by both dealers and customers.

Oil Sampling Interval

Take the oil samples as close as possible to the standard intervals. In order to receive the full value from S·O·S℠ oil analysis, you must establish a consistent trend of data. In order to establish a pertinent history of data, perform consistent oil samplings that are evenly spaced.

Note: Refer to the Operation and Maintenance Manual for your specific engine for recommended oil drain intervals.

Consult your Caterpillar dealer for complete information and assistance in order to establish an S·O·S℠ Services program for your engine.

More Frequent S·O·S℠ Sampling Improves Life Cycle Management

Traditionally, the suggested S·O·S℠ sampling intervals for diesel engines have been at 250 hours. However in severe applications, more frequent oil sampling is recommended. Severe service for lubricated compartments occurs at high loads, in high temperatures, and in dusty conditions. If any of these conditions or other severe service indicators exist, sample the engine oil at 125 hour intervals. These additional samples will increase the chance of detecting a potential failure.

Determining Optimum Oil Change Intervals

Sampling the engine oil at every 125 hours provides information for oil condition and for oil performance. This information is used to determine the optimum usable life of a particular oil. Also, more points of data will allow closer monitoring of component wear rates. Close monitoring also allows you to obtain the maximum use of the oil. For detailed information on optimizing oil change intervals, please consult your Caterpillar dealer.

Optimizing the Component Life Cycle

An increase in the number of oil samples provides a better definition of the trends in data between oil change intervals. More oil samples will allow you to closely monitor wear patterns of components. This action will ensure that the full life of the components are achieved.

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.

Table 3

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·S^{SM} 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. Refer to Table 3.

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℠ 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℠ 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 230°-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 D445.

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 a lack 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.

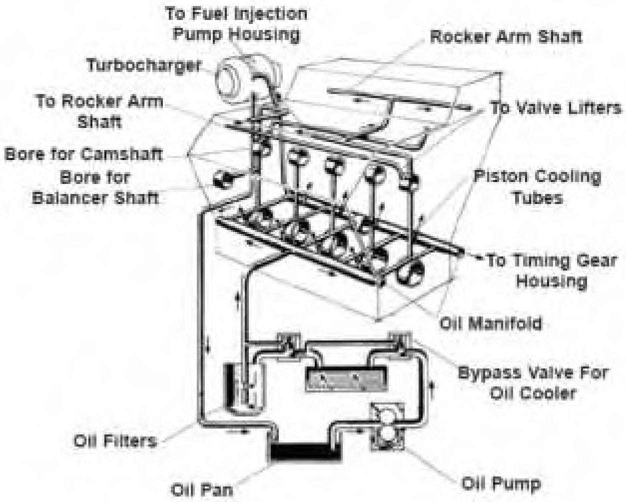

Illustration 11 g02142798

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 away some of the oil film. Particles of iron, steel, 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-laden 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.

Illustration 12 g02142802

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

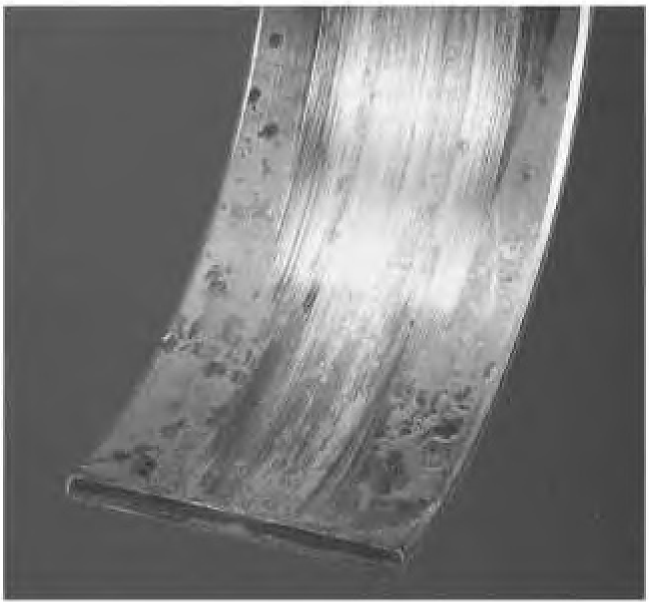

Illustration 13 g02142813

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

Illustration 14 g02142814

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

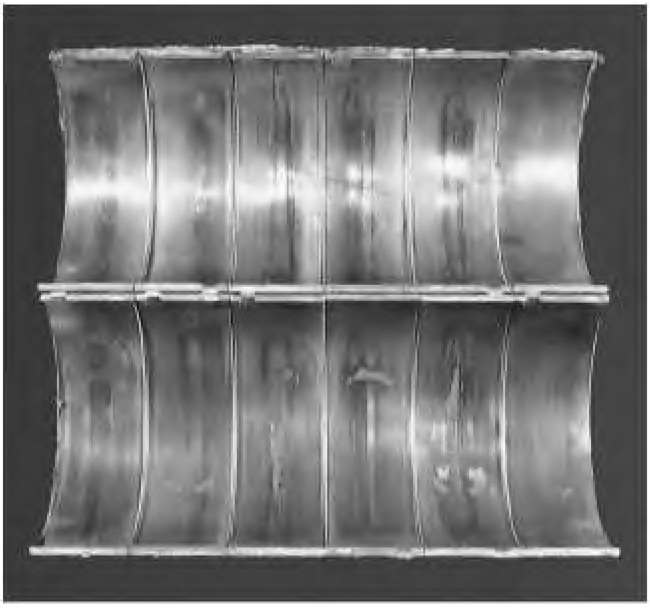

Illustration 15 g02142815

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

Illustration 16 g02142818

Scratched bearing surface. Notice embedded particles of debris.

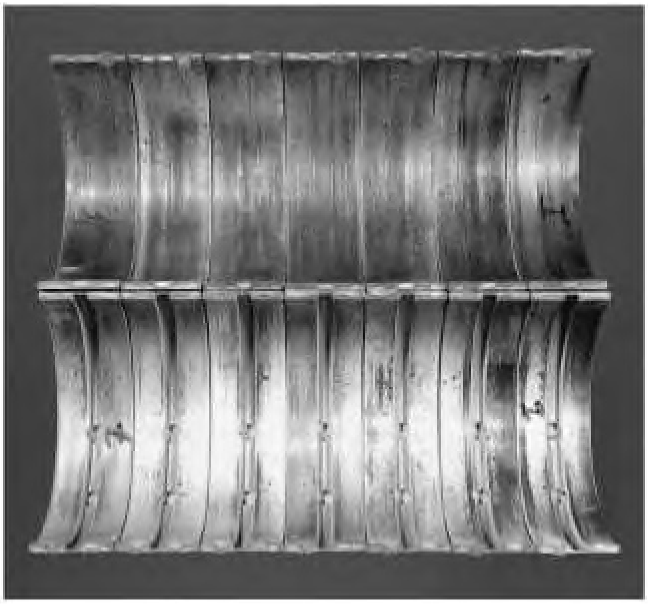

Illustration 17 g02142819

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

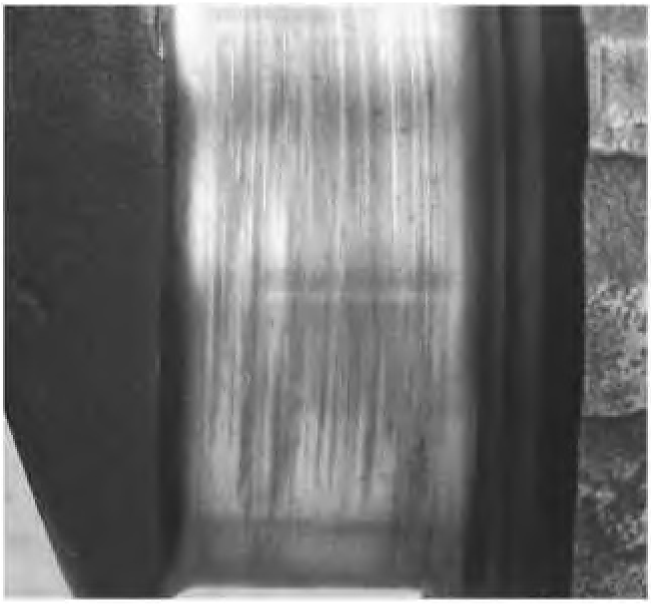

Illustration 18 g02142820

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 metalto- 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.

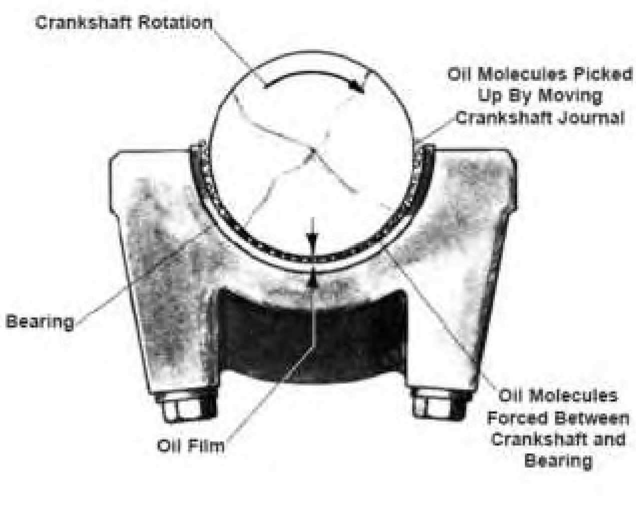

Illustration 19 g02142847

Oil film between crankshaft journal and bearings.

Illustration 20 g02142848
Result of oil starvation.

Illustration 21 g02142849
Deep circumferentail 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.

Illustration 22 g02142851

Piston skirt damaged by abrasive wear.

Illustration 23 g02142852

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

Illustration 24 g02142857

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

Illustration 25 g02142858

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 may be due to extended oil change intervals or improper oil performance classification selection.

Illustration 26 g02142860

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.

Illustration 27 g02142865

Deep scratches and damage to oil holes on bearings.

Illustration 28 g02142867

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 lubricating oil.

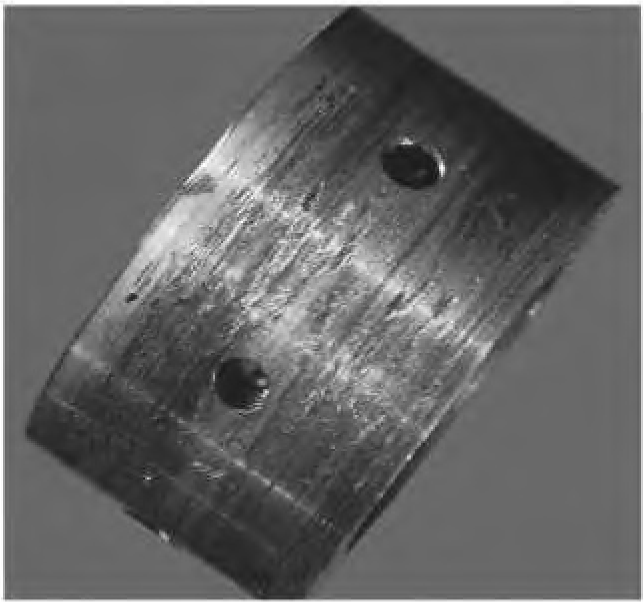

Illustration 29 g02142869

Lack of lubricant caused this journal bearing to be deformed.

Illustration 30 g02142871

Illustration 31 g02142873

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

Illustration 32 g02142875

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.

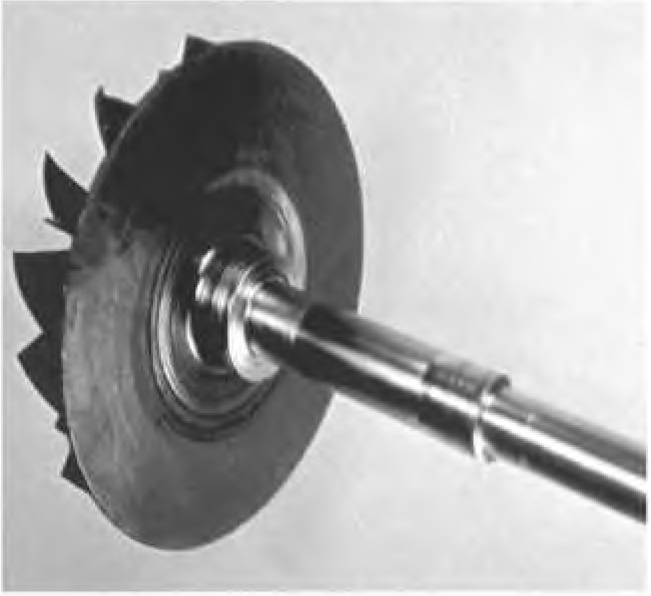

Illustration 33 g02142888
Heat discoloration on the shaft.

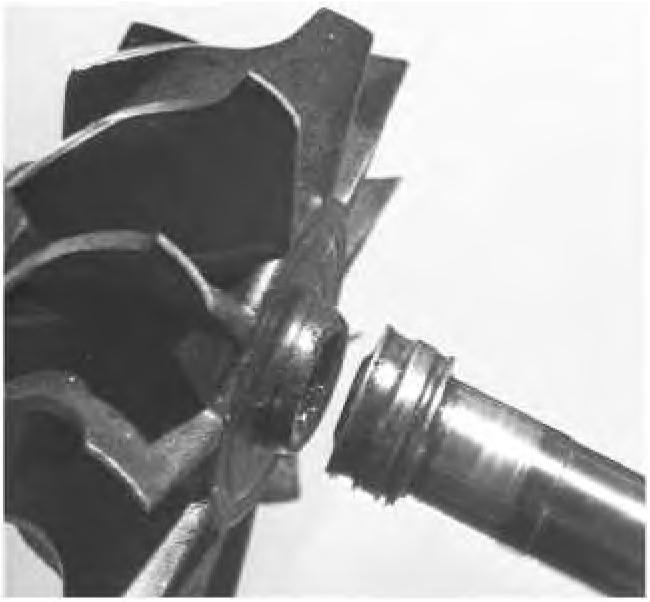

Illustration 34 g02142889
Shaft broke when contact on turbine hub, due to thrust bearing failure, weakened.

Illustration 35 g02142890

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

Illustration 36 g02142891

Scratches on both bearing journals ...dirty oil.

Illustration 37 g02142892

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

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 turbocharager; 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.

Illustration 38 g02142907

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

Illustration 39 g02142908

AiResearch. Wear grooves on surface of thrust washers.

Illustration 40 g02142909

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

Valves

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.

Illustration 41 g02142916

Valve guttering effect caused by excessive deposit formation.

Illustration 42 g02142918

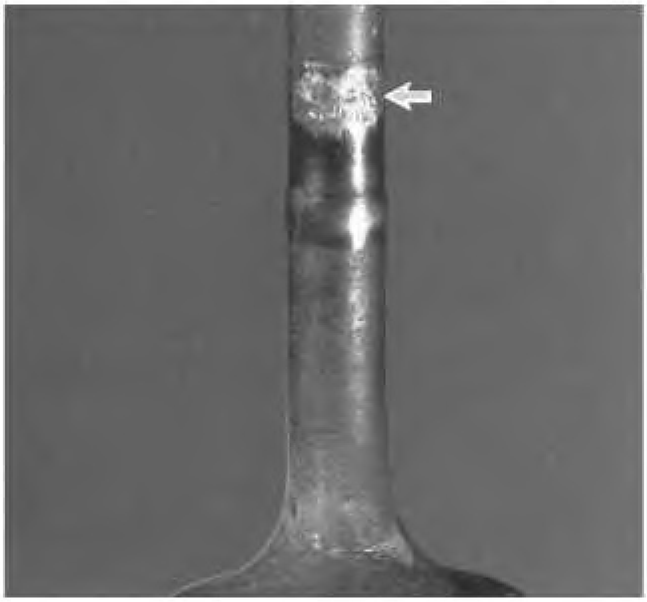

Illustration 43 g02142919

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 (DI) 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 new oil TBN must be 10 times the fuel sulfur level. The TBN is determined by the ASTM D2896 procedure.

Note: The minimum TBN of the new oil is 5 regardless of the fuel sulfur level. Illustration 44 demonstrates the TBN.

Note: TBN is also commonly referred to as Base Number (BN).

Use the following guidelines for fuel sulfur levels that exceed 1.0 percent:

- Choose a multigrade oil with the highest TBN that meets one of these specifications categories: Cat

ECF-2, Cat ECF-3, or API CJ-4

- Reduce the oil change interval. Base the oil change interval on the oil analysis. Ensure that the oil analysis includes the condition of the oil and a wear metal analysis.

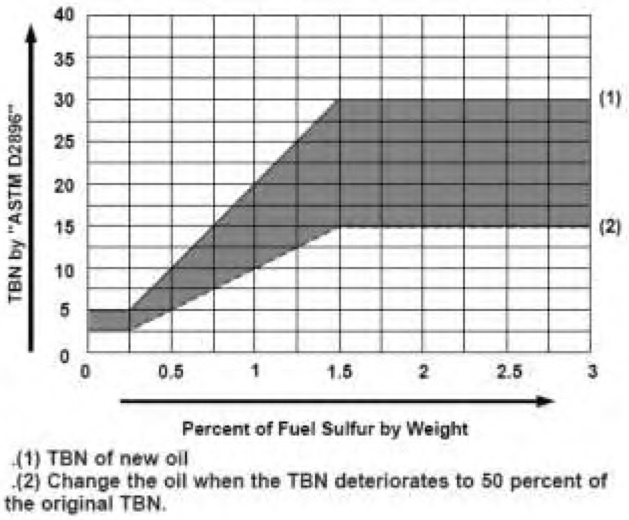

Illustration 44 g02143095

Excessive piston deposits can be produced by an oil with a high TBN and or high ash. These deposits can lead to a loss of control of the oil consumption and to the polishing of the cylinder bore.

Note: For the noncurrent on-highway PC (Precombustion Chamber) engines, the minimum new oil TBN must be 20 times the fuel sulfur level. The TBN is determined by the ASTM D2896 procedure. The minimum TBN of the new oil is 5, regardless of the fuel sulfur level.

NOTICE

Operating Direct Injection (DI) diesel engines on fuel with sulfur levels over 1.0 percent (10,000 ppm) may require shortened oil change intervals in order to help maintain adequate wear protection.

NOTICE

Cat 2007 and newer on-highway diesel engines are designed to operate only with fuel that has 0.0015 percent (15 ppm) or less sulfur. Refer to this Special Publication, Distillate Diesel Fuel (Fuel Illustration 1 Recommendations for On-highway Diesel Engines) article, and to this Special Publication, Frequently Asked Questions (Ultra Low Sulfur Diesel (ULSD) Fuel article.

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 D2896. Regardless of fuel sulfur level, the minimum TBN of new oil is 5. Refer to Illustration 45.

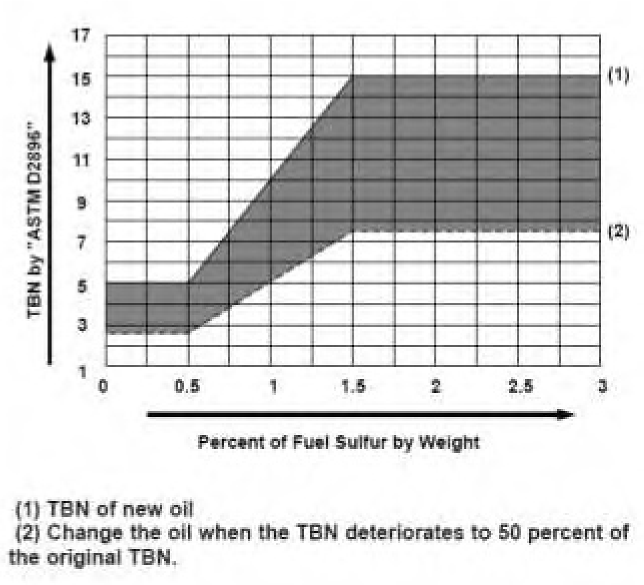

Illustration 45 g02143098

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 oilrelated 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.