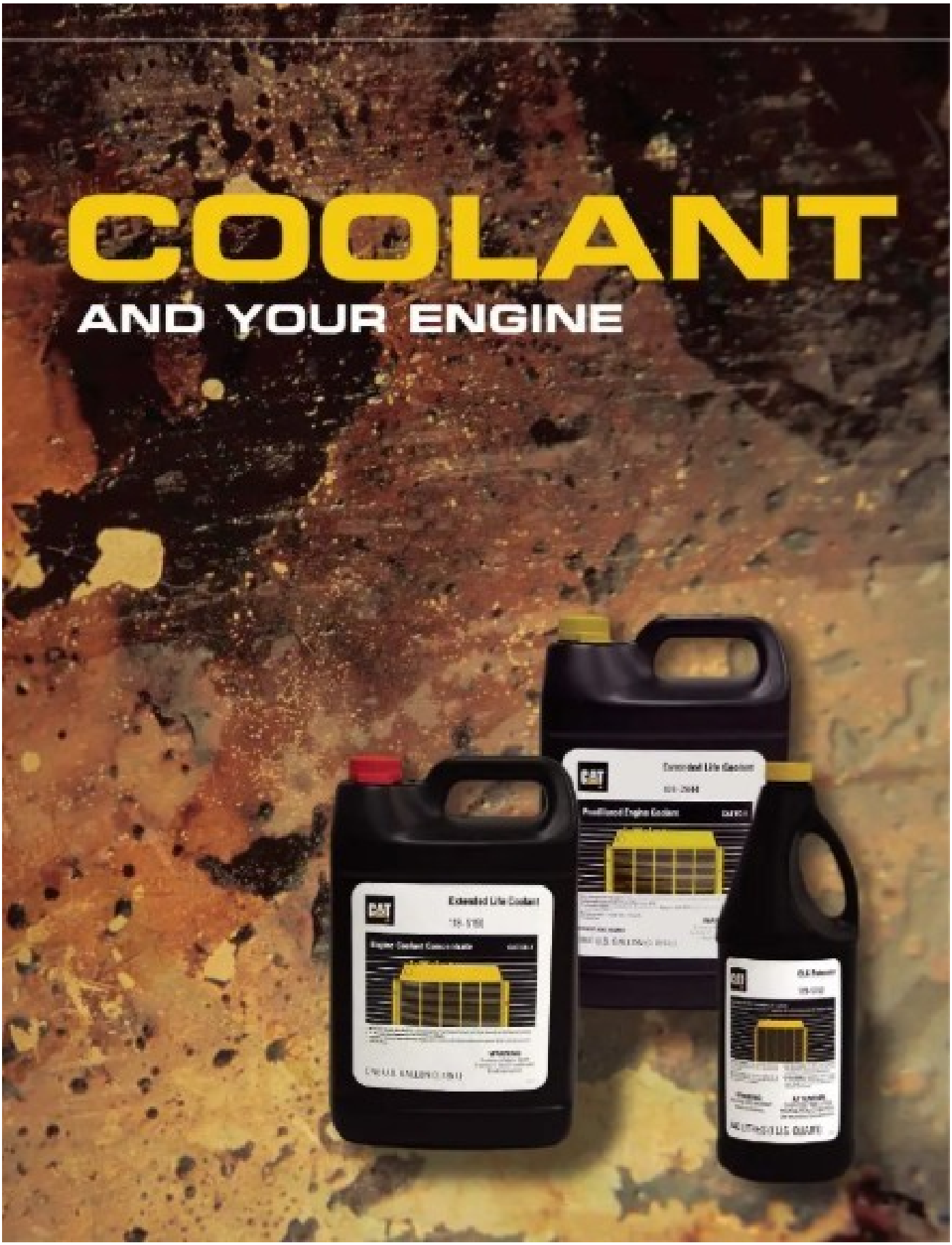
COOLANT

AND YOUR ENGINE



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Foreword

Diesel engine manufacturers have increased engine operating temperatures to improve engine efficiency. This means proper cooling system maintenance is especially important. Overheating, overcooling, pitting, cavitation erosion, cracked heads, piston seizures, and plugged radiators are classic cooling system failures.

Proper coolant selection and maintenance are your choice, and coolant is vital to successful engine service life. In fact, coolant is as important as the quality of your fuel and lubricating oil.

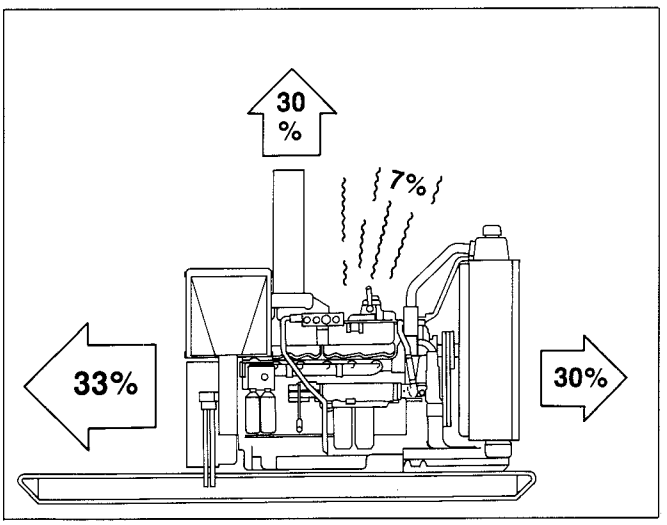
This booklet tells the coolant story: its composition, contamination and typical consequences. It also offers preventive measures to help you avoid the costly effects of coolant-related failures.

Understanding Cooling Systems

Proper cooling system design and maintenance is an important part of the satisfactory operation and service life of an engine. Understanding how the cooling system works can help reduce owning and operating costs.

Function

During operation, all internal combustion engines generate heat. This heat is developed by fuel combustion. The temperature of burning fuel in Caterpillar Engines can reach 1927°C (3,500°F). However, only about 33% of this total heat is converted into crankshaft horsepower. Approximately 30% is expelled through exhaust, while another 7% is radiated directly into the atmosphere from engine surfaces. The remaining 30% must be dissipated through a carefully-designed cooling system.



Proportional amount of heat dissipated from engine

In addition to removing heat generated from fuel combustion, in some applications the cooling system removes heat from numerous other sources. Other components that transfer heat to the coolant include:

- transmission oil coolers
- hydraulic oil coolers
- aftercoolers
- water-cooled exhaust manifolds
- water-cooled turbocharger shields and housings
- marine gear oil coolers
- torque converter/retarder coolers.

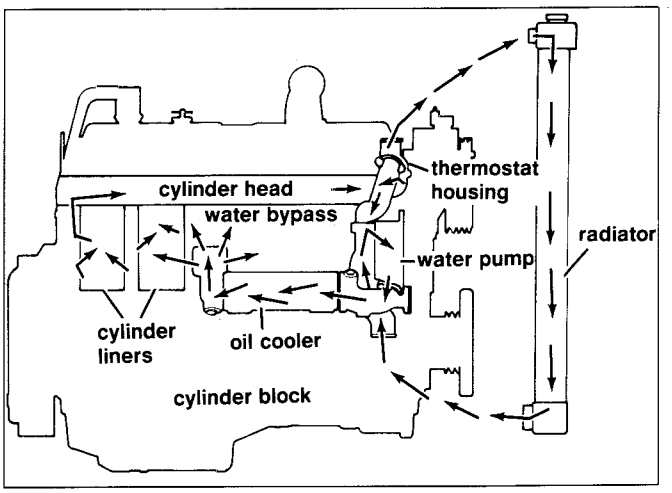
Thus, the function of the cooling system is to remove the proper amount of heat to keep the engine running at correct operating temperatures. This function is vital to the operation of an internal combustion engine.

Components and Operation

There are many types of cooling systems. Most systems remove heat through a radiator. Other types use a keel cooler, tube bundle, or cooling towers to remove heat. For most cooling systems, however, the basic components are:

- radiator
- fan
- coolant
- water pump
- engine oil cooler
- water temperature regulator (thermostat).

A typical cooling system operates by directing coolant flow through the engine and other components to absorb heat, and then routing the heated coolant into the radiator to cool down.

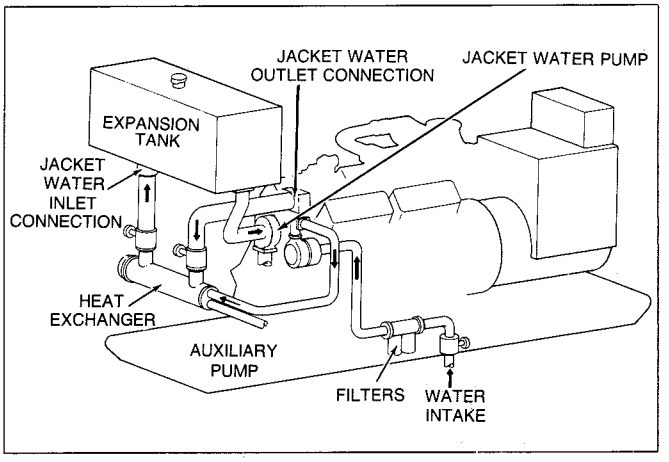


Schematic of a typical Caterpillar engine cooling system

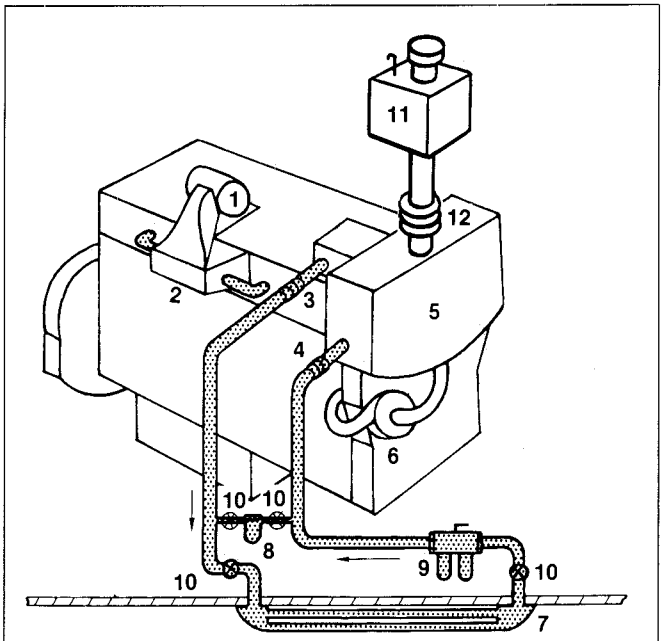
Flow of the coolant begins at the water pump and follows a path through the engine and other components. First, the coolant flows through the engine oil cooler, and then into the cylinder block. Next, the coolant goes through the cylinder block and into the cylinder heads. After flowing through the cylinder head, the coolant enters the radiator. Finally, the coolant completes its cycle when it reaches the water pump and begins to retrace its path.

During normal operation, the fan pushes or pulls air through the radiator fins and around the tubes that extend from the top to bottom of the radiator. (Some machines can have crossflow radiator cores.) When an engine is cold, temperature regulators prevent coolant flow to the radiator. After the coolant temperature becomes warmer, temperature regulators begin to open and allow some coolant flow to the radiator. The amount the regulator opens and percent of coolant flow to the radiator depends on engine load and ambient temperature, as well as performance of the radiator. When hot coolant flows through the radiator tubes, air movement across the tubes and fins lowers the coolant's temperature.

Some cooling systems operate in slightly different manners, but the basic principles are the same. In heat exchanger cooling systems, an expansion tank and heat exchanger perform the same function as the radiator. However, instead of transferring heat into the air, a heat exchanger system transfers coolant heat to an external water supply. In marine applications, a keel or skin cooler is used as an outboard heat exchanger, which is either attached to the submerged part of a vessel's hull or built as part of the hull.



Schematic of typical heat exchanger cooling system



Schematic of typical keel cooler cooling system

Cooling System Temperature

Cooling systems are designed to keep an engine operating within a desired temperature range. Temperature of the coolant must remain high to allow the engine to operate efficiently. However, temperature must stay low enough to prevent the coolant from boiling.

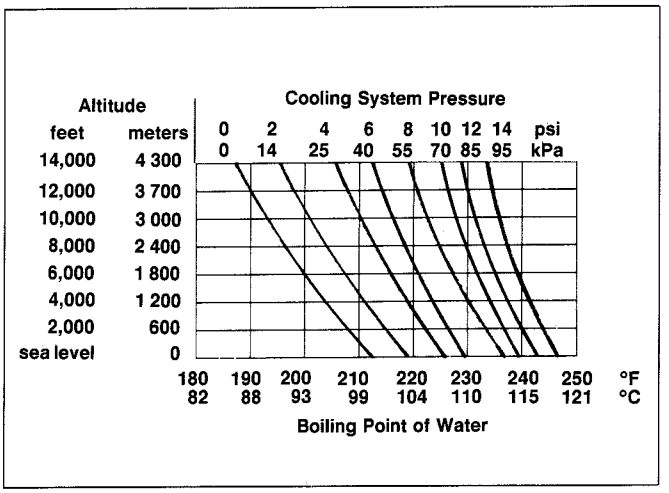
A cooling system regulates temperature by transferring heat from the engine to the coolant and, eventually, into the air (or external water supply). How quickly the system transfers heat from the coolant into the air directly affects the system's temperature. This rate of heat transfer at the radiator depends on many different factors.

A major factor of heat transfer is the difference between the temperature of coolant inside the radiator and the temperature of surrounding air. When the difference between coolant temperature and ambient temperature increases, the rate of heat transfer increases. Alternatively, when this temperature differential decreases, the rate of heat transfer declines.

If it starts to boil or steam, coolant is pushed out of the radiator's pressure relief valve. This lowers the level of coolant and leads to engine overheating. Once overheating begins, continued operation only worsens the condition.

The temperature at which coolant boils depends on three factors:

1. Pressure at which cooling system operates
2. Altitude at which cooling system operates
3. Amount and type of antifreeze in coolant mixture.



Relationship between pressure/temperature and altitude for water (without antifreeze)

Boiling point is higher at higher pressure levels. Hence, most cooling systems are designed to operate under pressure. Maximum pressure of the system is controlled by a valve in the radiator cap or by the pressure relief valve.

For systems without a pressure cap, boiling point is lower at higher altitudes. For example, at 1800 meters (6,000 feet) above sea level, water boils at 93°C (200°F). But at 3700 meters (12,000 feet), it boils at only 88°C (190°F).

Boiling Point of Coolant at Varying Antifreeze Concentrations	
% Concentration	Temperature at Which Coolant with Ethylene Glycol Will Boil[1]
20	103°C (217°F)
30	104°C (219°F)
40	106°C (222°F)
50	108°C (226°F)
60*	111°C (231°F)

[1] At sea level.
* Caterpillar recommends not to exceed 60% concentration.

Along with altitude and pressure, the type and amount of antifreeze added to water also changes the coolant's boiling point. Boiling point is higher with higher concentrations of ethylene glycol type antifreeze. However, ethylene glycol is less effective at transferring heat than water. Because of these effects on boiling point and heat transfer efficiency, correct concentration of ethylene glycol is crucial.

Coolant Properties

Generally, a coolant mixture consists of water combined with supplemental coolant additive (also called cooling system conditioner), or water mixed with both supplemental coolant additive and antifreeze. The type of coolant you select directly affects the efficiency and service life of both the cooling system and engine.

Water Content

Water is used in the coolant mixture because it is the most efficient, best known, and universally available heat transfer agent. However, each water source contains contaminant levels to various degrees. At operating temperatures of modern diesel engines, these contaminants form acids or scale deposits that can reduce cooling system service life.

Water can be used in a coolant mixture if contaminant levels are not excessive and proper cooling system maintenance is performed. Water used in coolant mixtures must conform to established levels for:

- chloride content
- sulfates content
- total hardness
- total solids
- pH level.

Water characteristics vary from area to area. For example, high chloride contents are usually found in coastal areas where saline treatment plants are used. It is possible for the chloride content to be 90 parts per million (ppm) in one area and as high as 1,200 ppm only 80 kilometers (50 miles) away. High sulfate contents are usually found in areas around coal mining operations. Water containing high levels of chlorides, sulfates, or totally-dissolved solids must be treated. Industrial divisions of many water companies have facilities to perform this water treatment service.

Water Testing

To determine water characteristics in your area, contact the city water department or an agricultural agent. Independent laboratories can also perform this testing service. Two of these companies are listed below, but there are others qualified to provide this service:

LOCC Corporation
905 Bayshore Drive
Coos Bay, Oregon 97420
(503) 267-4904

Nalco Chemical Co.
Naperville Technical Center
One Nalco Center
Naperville, Illinois 60566
ATTN: Sample Receiving
(312) 961-9500

Minimum Acceptable Water Characteristics for Use in Engine Cooling Systems

Properties	Limits	ASTM[1] Test Methods
Chloride (Cl), gr/gal (ppm)	2.4 (40) max	D512b, D512d, D4327
Sulfate (SO4), gr/gal (ppm)	5.9 (100) max	D516b, D516d, D4327
Total Hardness, gr/gal (ppm)	10 (170) max	D1126b
Total Solids,gr/gal (ppm)	20 (340) max	D1888a
pH	5.5 - 9.0	D1293

[1]American Society for Testing and Materials

Most laboratories need a water sample size of approximately 250 ml (½ pint). These laboratories may be able to provide mailer packages for the water samples (contact them for mailing information). Tests from the Standards Methods for the Examination of Water and Wastewater, published by the American Public Health Association, and the 1981 Annual Book of the American Society for Testing and Materials are references for determining water characteristics (see page 31).

Caterpillar recommends using distilled or deionized water to help reduce the potential and severity of chemical insolubility. Mixed bed filters or reverse osmosis procedures are preferred water treatment methods.

In remote areas only, where distilled, deionized or treated water is not available, use the following guidelines:

1. Never use salt water.
2. Select the best quality fresh water available. Use water analysis to define water quality.
3. NEVER USE WATER ALONE AS A COOLANT. Supplemental coolant additives are required because water is corrosive at engine operating temperatures.

Supplemental Coolant Additive Content

After acceptable water has been found, it must be mixed with either a supplemental coolant additive (also called cooling system conditioner) or a supplemental coolant additive and antifreeze.

Supplemental coolant additives must be added to all coolant mixtures. However, adding coolant additives to poor quality water does not make the water acceptable. Coolant additives can help poor quality water, but protection against corrosion and pitting is unlikely. When salt concentration in the coolant mixture is more than 200 ppm, because of the addition of water or evaporation, supplemental coolant additive has limited effect. When this condition exists, the cooling system must be drained, flushed until clean, and then filled with new coolant.

Caterpillar's supplemental coolant additive helps prevent rust, scale and mineral deposits from forming. It helps protect all metals, including aluminum, from corrosion. In addition, it will not affect gaskets or hoses. The solution is compatible with glycol base antifreeze. Caterpillar's supplemental additive is available in five container sizes from Caterpillar dealers.



Caterpillar's supplemental coolant additive

Available Quantities of Supplemental Coolant Additive	
Part No.	**Size**
6V3542	0.25 liter (0.53 pint)
8T1589	0.47 liter (1 pint)
3P2044	1.00 liter (1.05 quart)
8C3680	18.95 liter (5 gallons)
5P2907	208 liter (55 gallons)

Caterpillar's additive and antifreeze are not intended for use in gasoline engines. The antifreezes available for the commercial automotive market should be used for all gasoline engines. Follow the manufacturer's recommendation for any supplemental additives and for the coolant change period.

When using Caterpillar Antifreeze, no precharge elements are required. Caterpillar Antifreeze contains the necessary amount of supplemental coolant additives at initial fill (see page 12). However, maintenance elements are still required. Using the wrong size element can result in over-concentration of additives.

Supplemental coolant additive element assemblies are also available from Caterpillar for use instead of liquid coolant additives in some applications. Element assemblies are in a dried state and dissolve into the coolant when it passes through the filter. Use precharge elements at original fill, and use other elements as maintenance items at specific service intervals. Elements can be identified by part number or element length. In marine applications, Caterpillar recommends using a liquid supplemental coolant additive.

Amount of Supplemental Coolant Additive Needed for Pre-mixed Coolant Solution		
Cooling System Capacity liter (gal)	**Amount at Initial Fill**	**Approximate Amount at 250 Hour Maintenance[1]**
22 - 32 (6-8)	3P2044 (1 Bottle)	6V3542 (1 Bottle)
33 - 47 (9-12)	3P2044 (2 Bottles)	6V3542 (1 Bottle)
48 - 62 (13-16)	3P2044 (2 Bottles)	8T1589 (1 Bottle)
63 - 85 (17-22)	3P2044 (3 Bottles)	8T1589 (1 Bottle)
86 -115 (23-30)	3P2044 (4 Bottles)	6V3542 (3 Bottles)
116 -165 (31-43)	3P2044 (5 Bottles)	3P2044 (1 Bottle)
166 -244 (44-64)	3P2044 (8 Bottles)	3P2044 (2 Bottles)

[1] Do not exceed 6% maximum concentration. See supplemental coolant additive Test Kit on page 29.

NOTE: For all other engine applications at original fill, use one pint of supplemental coolant additive for every four gallons of cooling system capacity (3% concentration).



Supplemental Coolant Additive Element Assembly

At original fill, precharge elements must be used (except when using Caterpillar Antifreeze). The precharge establishes a protection level between a minimum of 0.030 liter per 3.8 liters (1.0 ounce per gallon) and a maximum of 0.059 liter per 3.8 liters (2.0 ounces per gallon). Use precharge elements only at original fill or after the system has been drained and refilled.

Precharge elements are necessary at original fill and after the system has been drained and refilled because maintenance elements do not supply sufficient amounts of coolant additives. If the cooling system lacks the necessary concentration of coolant additives, some surfaces have protection against corrosion and pitting at the expense of other surfaces.

Supplemental Coolant Additive Elements By Capacity		
Cooling System Capacity liter (gal)	Initial[1] Precharge Element	250 Hour Maintenance Element
22 - 32 (6-8)	9N6123 (1)	9N3368 (1)
33 - 47 (9-12)	9N6123 (1)	9N3718 (1)
33 - 47 (9-12)	*7E6013 (1)	*7E6014 (1)
48 - 62 (13-16)	9N3366 (1)	9N3368 (1)
63 - 85 (17-22)	9N3367 (1)	9N3368 (1)
86 -115 (23-30)	9N3367 (1)	9N3718 (1)
116 -165 (31-43) or 116 -165 (31-43)	9N3367 (2) 9N3367 (1)	9N3368 (2) 9N6123 (1)
166 -244 (44-64)	9N3367 (2)	9N3718 (2)

[1] When using Caterpillar Antifreeze, no precharge elements are required.

* 7E6013 and 7E6014 Supplemental Cooling Additive Elements contain silicates to protect higher aluminum content engines.

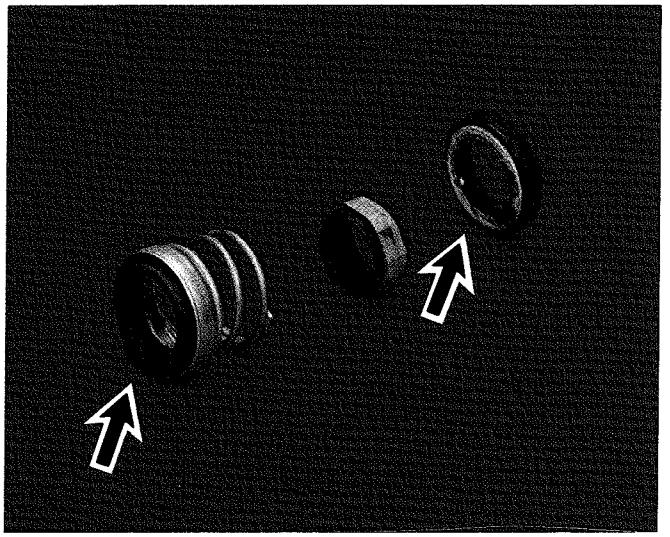
NOTE: One 9N3668 base assembly is required for all capacities listed, except for 116-165 liters (31-43 gallons) and 166-244 liters (44-64 gallons), which each require two. Also, all capacities require two 9N3666 Valve Assemblies.

A 3% to 6% concentration of liquid supplemental coolant additive is required during the original fill of the cooling system mixture. This initial concentration of supplemental additive is vital. If the concentration of additive is too high, insoluble salts form and can cause wear on water pump seal surfaces. Engine damage can also result when the concentration of supplemental coolant additive or antifreeze exceeds recommended levels.

NOTE: Higher aluminum content engines require silicates to protect aliminum surfaces. Supplemental coolant additive used on these engines must pass the following tests:

ASTM D1384 - Glassware corrosion test
ASTM D2809 - Cavitation Erosion Of Aluminum
ASTM D4340 - Hot Surface Corrosion Of Aluminum

In addition to controlling cast iron cylinder liner and block pitting, and cavitation erosion.



This water pump seal's deterioration was accelerated by precipitated additives. Cause is excessive additive or antifreeze concentrations.

Caterpillar offers a Coolant Additive Test Kit (see page 29). This test is a simple and accurate method for determining the concentration of nitrates in the coolant additives and ethylene glycol in the coolant mixture. Many other commercially available procedures are available to determine supplemental coolant additive concentrations.

Over a period of time, the concentration of coolant additives is depleted. This occurs because additives experience repairing breaks during the coating of metal surfaces, and from continuously neutralizing acids that form in the system. Therefore, to maintain constant protection, it is necessary to periodically replenish the additive concentration. Add 0.47 liter (1 pint) of additive for every 75.8 liters (20 U.S. gallons) of coolant at recommended intervals or 16,000 to 19,000 kilometers (10,000 to 12,000 miles), or at 250 Service Meter Hours. Follow container instructions for the correct concentration. (See page 25, "Periodic Maintenance.")

Supplemental Coolant Additive and Element Assemblies Available from Caterpillar			
Part No.	**Description**	**Amount of Additive**	**Length of Element**
9N3366	Supplemental Coolant Additive Element Assembly	453 g (16 oz)	175 mm (6.9")
9N3367	Supplemental Coolant Additive Element Assembly	906 g (32 oz)	201 mm (7.9")
9N3368	Supplemental Coolant Additive Element Assembly	113 g (4 oz)	133 mm (5.25")
9N3718	Supplemental Coolant Additive Element Assembly	226 g (8 oz)	175 mm (6.9")
9N6123	Supplemental Coolant Additive Element Assembly	340 g (12 oz)	175 mm (6.9")
7E6013	Supplemental Coolant Additive Element Assembly	340 g (12 oz)	175 mm (6.9")
7E6014	Supplemental Coolant Additive Element Assembly	226 g (8 oz)	175 mm (6.9")

NOTE: Soluble oil must not be used as a supplemental coolant additive in Caterpillar Engines because it damages radiator hoses and certain engine seals. Also, it does not lubricate pump bearings or protect engine parts from damage caused by cavitation erosion.

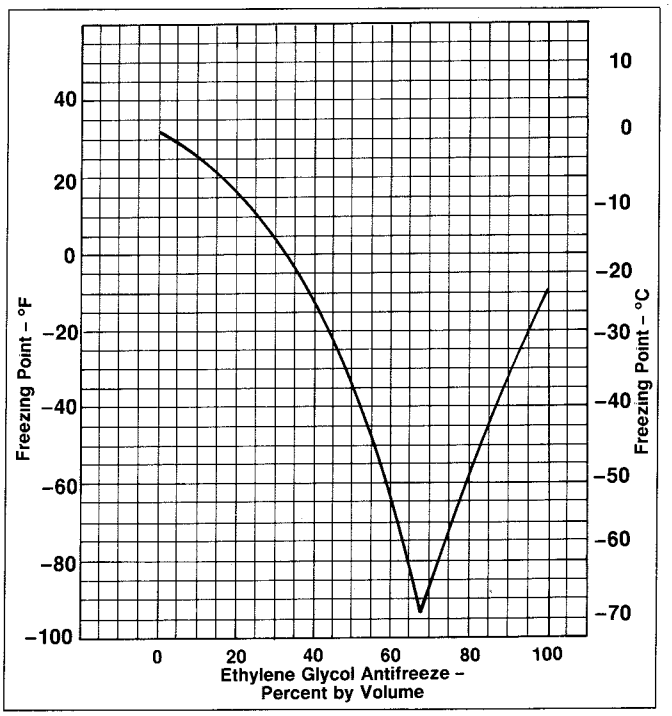
Antifreeze Content



Caterpillar Antifreeze

One purpose of antifreeze is to protect the engine coolant from freezing. The agent most commonly used for freeze protection is ethylene glycol. The relative concentrations of ethylene glycol and water are crucial to determining the amount of freeze protection a mixture will give.

Antifreeze also raises the boiling point of water and helps prevent water pump cavitation. All Caterpillar engines with air-to-air after cooling (ATAAC) require a 30% minimum concentration of antifreeze to prevent water pump cavitation.



Freezing point curve for typical ethylene glycol solution.

Caterpillar Diesel Engine[1] Antifreeze Protection Chart (Fahrenheit)

Gallons or Quarts Antifreeze Concentrate

Cooling System Capacity (gallons or quarts)

	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
6	5	-34																
7		-18	-54															
8		-7	-34															
9		0	-20	-47														
10		5	-12	-34	-62													
11			-5	-22	-44													
12			0	-16	-34	-56												
13			3	-8	-24	-44												
14				-5	-18	-34	-53											
15				0	-13	-26	-42	-62										
16				3	-7	-20	-34	-50										
17					-3	-14	-26	-42	-59									
18					0	-10	-20	-34	-47									
19					3	-7	-16	-26	-39	-56								
20					5	-3	-12	-22	-34	-47	-62							
21						0	-8	-18	-26	-39	-53							
22						2	-5	-14	-22	-34	-44	-59						
23						5	-3	-10	-18	-28	-39	-50						
24							0	-17	-16	-24	-34	-44	-56					
25							2	-5	-12	-20	-28	-39	-50	-62				
26							3	-1	-8	-16	-24	-34	-44	-56				
27								0	-7	-14	-20	-28	-39	-47	-59			
28								2	-5	-10	-18	-24	-34	-42	-53			
29								3	-1	-8	-14	-22	-28	-39	-47	-59		
30								5	0	-7	-12	-18	-26	-34	-42	-53	-62	
31									2	-3	-10	-16	-22	-28	-39	-47	-56	
32									3	-1	-7	-14	-20	-26	-34	-42	-50	-59

Caterpillar Diesel Engine[1] Antifreeze Protection Chart (Celsius)

Gallons or Quarts Antifreeze Concentrate

Cooling System Capacity (gallons or quarts)

	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
6	-15	-37																
7		-28	-48															
8		-22	-37															
9		-18	-29	-44														
10		-15	-24	-37	-52													
11			-21	-30	-42													
12			-18	-27	-37	-49												
13			-16	-22	-31	-42												
14				-21	-28	-37	-47											
15				-18	-25	-32	-41	-52										
16				-16	-22	-29	-37	-46										
17					-19	-26	-32	-41	-51									
18					-18	-23	-29	-37	-44									
19					-16	-22	-27	-32	-39	-49								
20					-15	-19	-24	-30	-37	-44	-52							
21						-18	-22	-28	-32	-39	-47							
22						-17	-21	-26	-30	-37	-42	-51						
23						-15	-19	-23	-28	-33	-39	-46						
24							-18	-22	-27	-31	-37	-42	-49					
25							-17	-21	-24	-29	-33	-39	-46	-52				
26							-16	-18	-22	-27	-31	-37	-42	-49				
27								-18	-22	-26	-29	-33	-39	-44	-51			
28								-17	-21	-23	-28	-31	-37	-41	-47			
29								-16	-18	-22	-26	-30	-33	-39	-44	-51		
30								-15	-18	-22	-24	-28	-32	-37	-41	-47	-52	
31									-17	-19	-23	-27	-30	-33	-39	-44	-49	
32									-16	-18	-22	-26	-29	-32	-37	-41	-46	-51

[1]Also for use in natural gas engines

NOTE: For larger cooling systems, find quarts or gallons needed for one-half of capacity, and then double that number of quarts or gallons.

As the use of ethylene glycol developed in the early 1970s, inhibitors were added to help prevent corrosion on engine parts. This type of coolant was successful until the late 1970s and early 1980s. At that time the automotive industry began weight and cost reduction programs that caused critical aluminum components like blocks and heads to be exposed to the cooling system. Due to this change of component material, the industry developed an antifreeze to protect aluminum components. This new antifreeze resulted in much higher dissolved chemical solids than former antifreezes.

Unfortunately, when this new antifreeze was mixed with supplemental coolant additives as suggested in maintenance practices, an over-concentration of cooling system inhibitors could result. When an over-concentration does occur, inhibitors can drop out of solution. This over-concentration can cause the following problems in cooling systems:

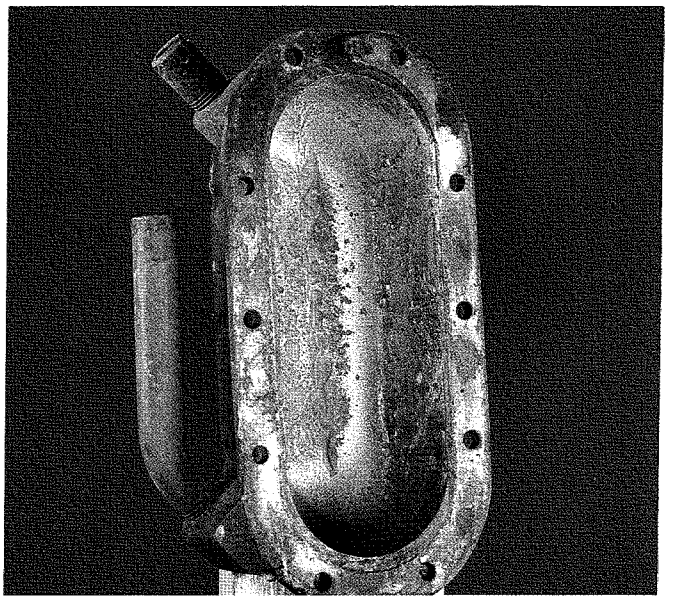
- reduction in heat transfer due to chemical deposits, chemical precipitates and silica gel
- premature water pump seal leakage or failure due to precipitates and chemical deposits on the seal face.

These problems have been linked to silicates and silicate gel, but the fundamental problem is over-concentration, not only over-concentration of silicates but of all the chemical additives used as inhibitors. To correct this problem, an overall reduction of cooling system additives is required. To accomplish acceptable performance the following is recommended:

- For commercial antifreeze use a low silicate antifreeze meeting the GM6038M specification.
- Follow engine manufacturer's recommendations regarding the use of supplemental inhibitors. Never use both Caterpillar's liquid and solid (spin-on water filter elements) inhibitors together.
- If other than Caterpillar supplemental coolant additive is used, follow the supplier's recommendation for the treatment and test evaluation. Do not mix corrosion additives within a cooling system; select an effective one and then use it exclusively.
- Use only enough antifreeze to meet freeze protection requirements. Never use over 60% by volume.
- Never top up with pure antifreeze. Premix antifreeze and water for makeup to provide the same freeze protection that's in your cooling system.
- Use water that meets the minimum quality level (see page 8).

Protection Temperatures for Antifreeze Concentrations[1]	
Protection to:	**Concentration**
-15°C (5°F)	30% antifreeze, 70% water
-24°C (-12°F)	40% antifreeze, 60% water
-37°C (-34°F)	50% antifreeze, 50% water
-52°C (-62°F)	60% antifreeze, 40% water

[1] Ethylene glycol-based antifreeze



This residual on a failed oil cooler formed from over-concentration of antifreeze in coolant mixture and blocked coolant flow through the cooling tubes

To combat the problem of over-concentration of coolant inhibitors, Caterpillar has introduced an antifreeze for use in all types of heavy-duty diesel engines. This antifreeze was specifically formulated as a solution to cooling problems resulting from over-concentration of inhibitors.

The combination of Caterpillar Antifreeze and supplemental coolant additive is a chemical system designed to work together for optimum performance. Caterpillar Antifreeze is ethylene-glycol based to protect against freezing. It contains anti-foam agents and the proper amount of protection against metal corrosion. It has enough protection against corrosion for aluminum parts in diesel engines, but not so much that chemicals drop out of solution and form harmful deposits.

Caterpillar Antifreeze also has built-in corrosion protection against cylinder liner and block pitting. With this protection, coolant conditioner is not required on the initial fill with Caterpillar Antifreeze. Simply add conditioner at the first 250 hours and each successive 250 hours when needed.

Caterpillar Antifreeze is available in a one gallon (3.8 liters) container (Part No. 8C3684), and a 55-gallon (208.5 liters) drum (Part No. 8C3686).

Propylene Glycol

With the shortage of ethylene glycol and the increased price, propylene glycol can be substituted as conditions dictate. With a 50/50 mixture with water, both ethylene and propylene glycols have very similar fluid properties relative to heat transfer, freeze protection, corrosion control and seal compatibility.

If propylene glycol is selected for the cooling system, the following recommendations are made:

1. Use in a similar manner as ethylene glycol based antifreezes.
2. Do not use in a higher concentration than a 50/50 propylene/water mixture because of the lower thermal conductivity of pure propylene glycol.
3. Use Caterpillar's supplemental corrosion inhibitor or equivalent for protection of cooling system components. The Caterpillar test kit can be used for monitoring inhibitor concentration for the Caterpillar Supplemental Coolant Additive.
4. The measurement of the freeze protection with propylene glycol must be made with a refractive-type meter (Cat 5P0957 or 5P3514 testers). The hydrometer type tester will not evaluate the propylene glycol mixture.
5. Although ethylene and propylene glycols can be mixed, it is better to maintain a single fluid system for evaluation of fluid properties.

Functional Effects

Without careful selection and maintenance of coolant, certain functional effects can cause problems in the cooling system. Coolant mixtures must be formulated to minimize the possibility of problems like:

- pitting and cavitation erosion
- rust
- acidity-alkalinity imbalance
- galvanic and electrolytic corrosion
- scale and deposit formation
- aeration.

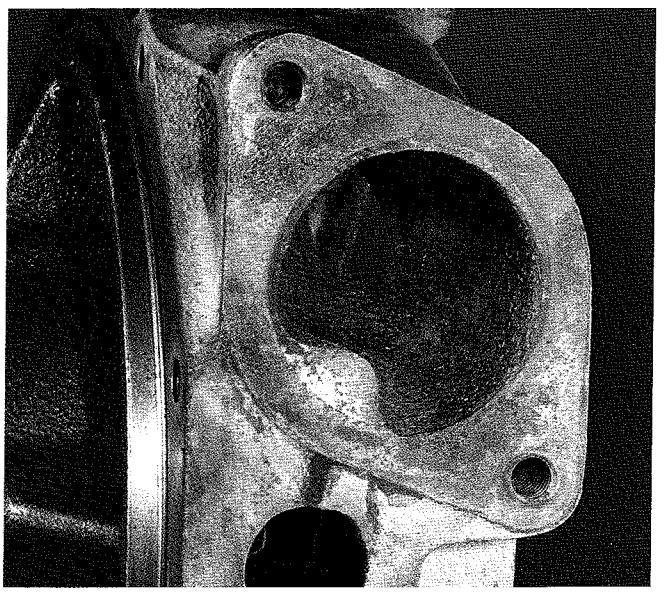
Using acceptable water and correct additives helps prevent these functional effects.



Failure-causing corrosion on a precombustion chamber caused by lack of supplemental coolant additive in the cooling system



Rust and scale deposits in absence of supplemental coolant additive caused temperature regulators to fail.



Corrosion on a water pump passage due to lack of supplemental coolant additive in the cooling system

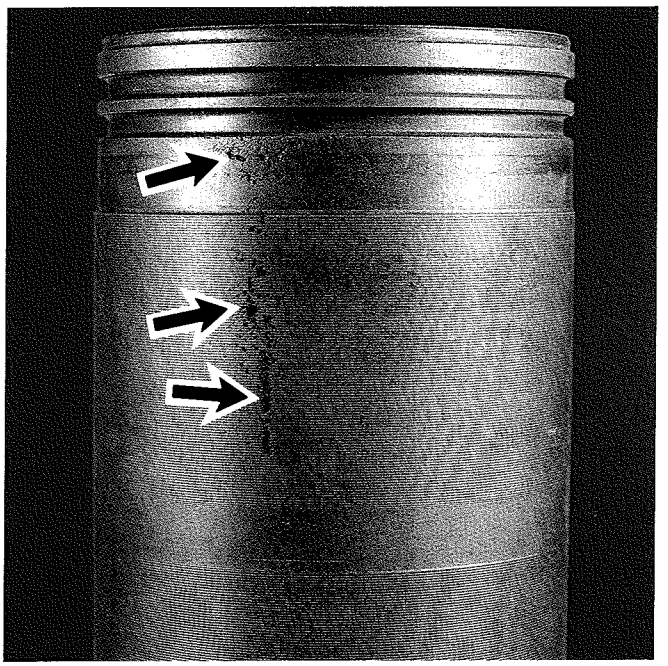
Corrosion is a chemical or electrochemical action that gradually wears away metal surfaces in the cooling system. In some instances, corrosion can eventually destroy an engine. All cooling system components need protection from corrosion. Supplemental coolant additives are used to protect metal surfaces. They coat these surfaces and neutralize contamination that develops in the coolant.

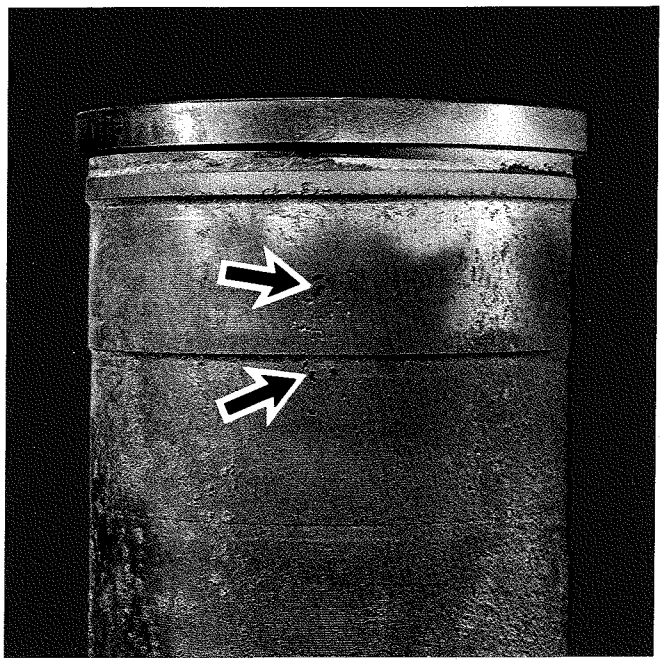
Types of corrosion are pitting and cavitation erosion, rust, acidity-alkalinity imbalance, and galvanic and electrolytic corrosion. Other functional effects are aeration and the formation of scale and deposits.

Pitting and Cavitation Erosion

Electrical current flow in a localized area causes pitting corrosion. Pitting is the most damaging type of corrosion. After pitting has progressed for any appreciable length of time, there is no practical way to stop it before perforation takes place. Because one ampere of current flowing for thirty hours removes one ounce of iron, current flow concentrated on a small area is very destructive. Therefore, prevention is the best policy.

Erosion-corrosion is a combination of mechanical and chemical or electrochemical action that causes corrosion. Cavitation is a particular type of erosion-corrosion and a common cause of cylinder wall pitting.

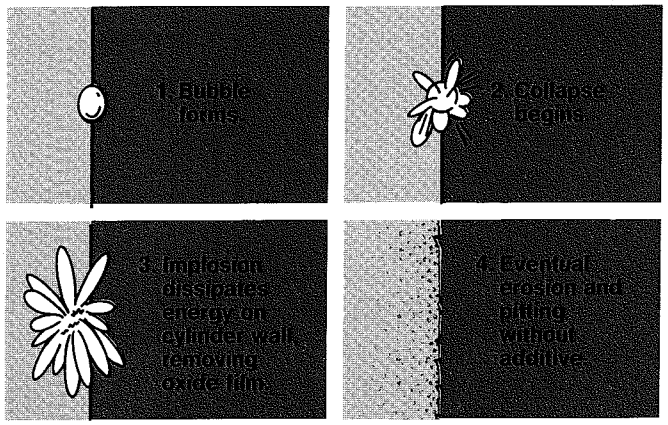




Examples of cylinder wall cavitation erosion

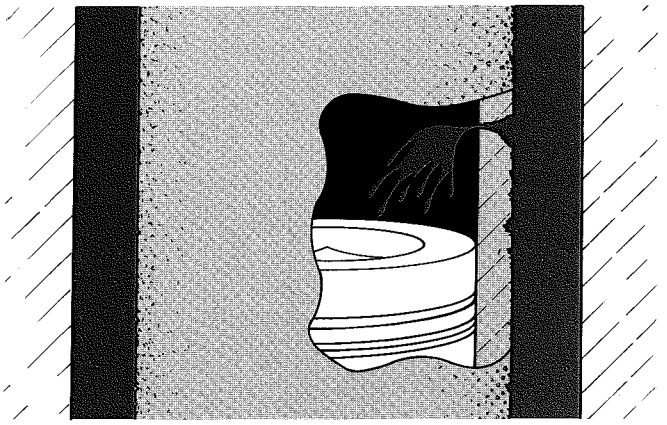
Cavitation of the cylinder wall begins when air bubbles remove the wall's protective oxide film. Flexing of the cylinder wall after the fuel mixture explodes in the combustion chamber causes cylinder wall vibration and creates air bubbles in the coolant. Concentration of air bubbles increases when cooling system pressure is low or when the system leaks. Also, increased vibration amplifies the quantity of air bubbles. Vibration multiplies when the engine is run cold, because of increased piston-to-cylinder clearance. Vibration also multiplies when the engine is lugged.

These air bubbles form on the outside of the cylinder wall (perpendicular to the wrist pin) and then explode inward, or implode. When air bubbles continue to implode, sufficient energy is released to physically attack the cylinder wall and remove the oxide film. Corrosion and pitting then take place at a high rate.



Progression of cavitation and pitting on cylinder wall.

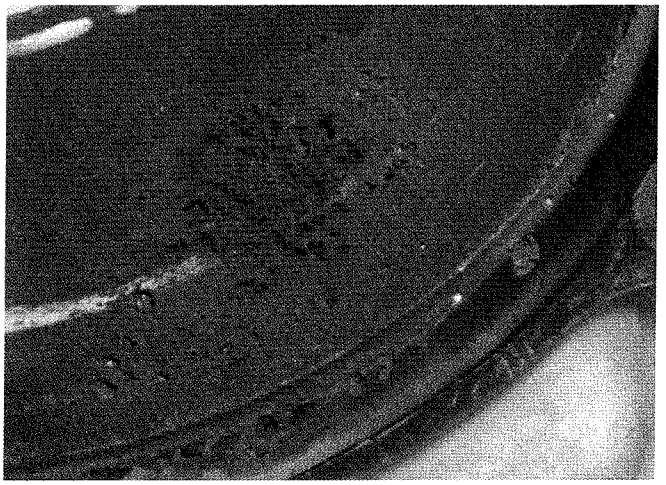
Eventually, a pit can become deep enough to break through the cylinder wall and allow coolant to leak into the cylinder. This coolant leak contaminates the lubricating oil.



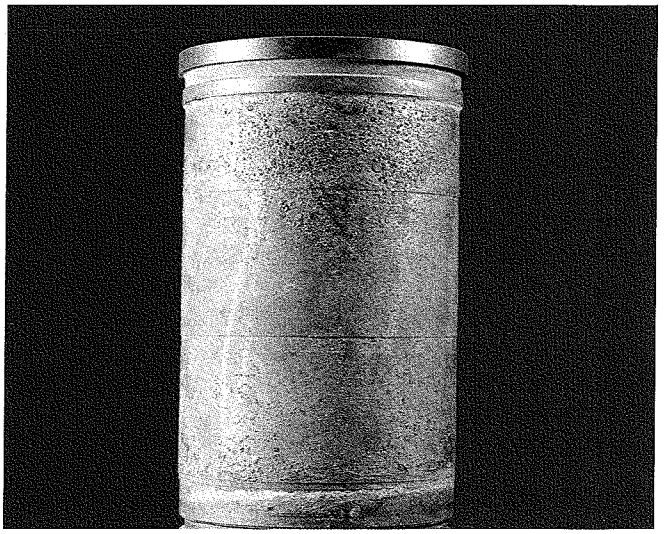
Eventually, a pit can penetrate the cylinder wall and allow coolant to leak into the cylinder.

Supplemental coolant additives coat metal surfaces and control cavitation-erosion and pitting. Unfortunately, small particles or ferrous scale often shield the surfaces underneath from the protective action of coolant additives. If this condition persists, pits can form. Keeping your cooling system clean, along with regularly replenishing your coolant additives, helps prevent pitting. However, if coolant additives are not added at the proper intervals and in correct quantities (see page 9), cavitation erosion and pitting intensifies. Eventually, coolant can penetrate the cylinder wall and cause major damage to the engine.

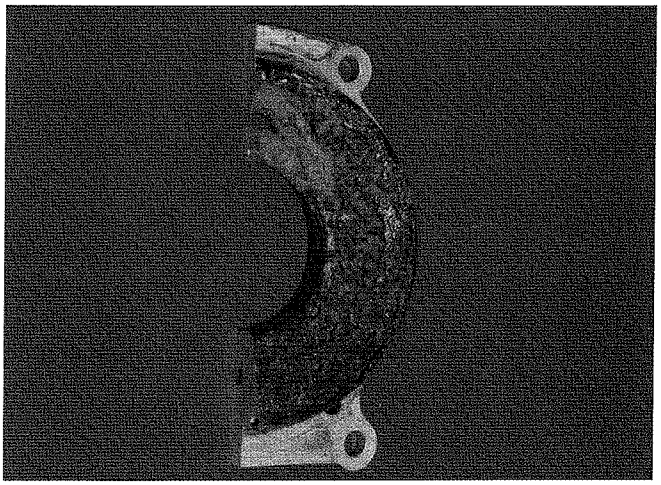
Caterpillar supplemental coolant additive helps prevent pitting.



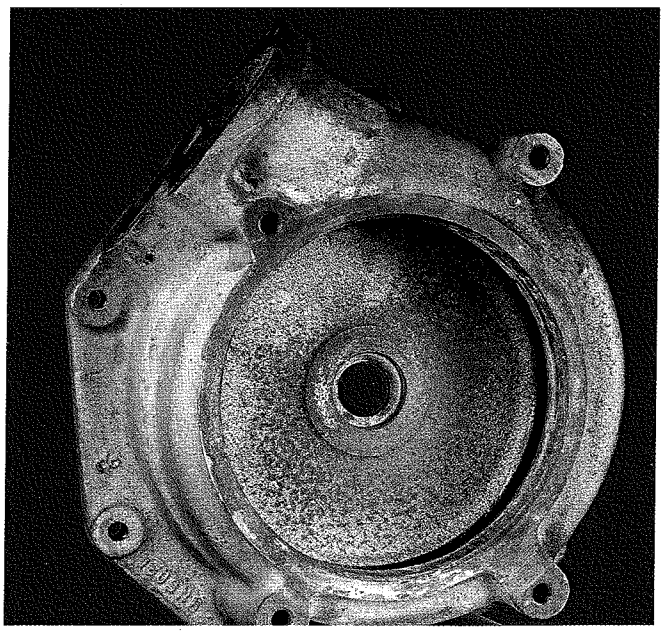
Effects of improperly treated cooling system involving engine laboratory tests.



Rust deposits on outside cylinder wall surface.



Corrosion/erosion of aluminum material 3406 Water Pump Adapter (4W4774).



Rusting inside water pump

Rust

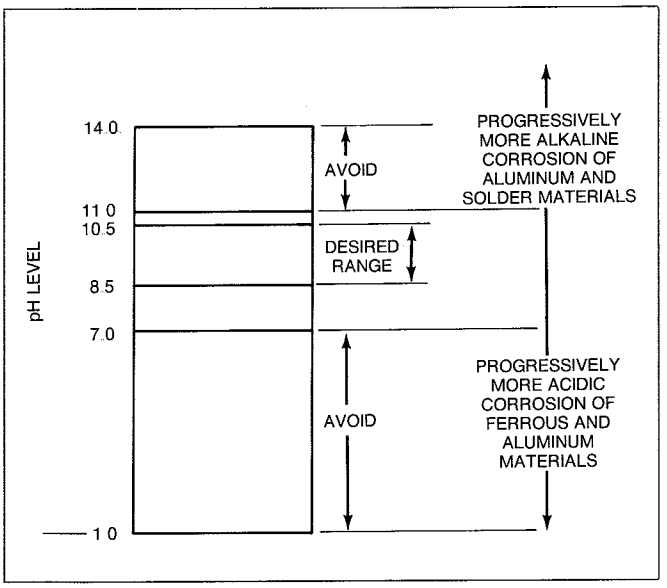
Rust is caused by oxidation within the cooling system. Heat and moist air accelerate this process. Rusting leaves residual scale deposits that can clog the cooling system. This causes accelerated wear and reduces the efficiency of heat transfer.

Caterpillar's supplemental coolant additive helps prevent rust in cooling system passages.

Acidity-Alkalinity Imbalance

A coolant mixture's acidity-alkalinity content is measured by its pH level. The pH level, ranging from 1 to 14, indicates the degree of acidity or alkalinity and the coolant's corrosiveness. For best results, the cooling system's pH level should be maintained between 8.5 and 10.5. When the pH level is above 11.0, the coolant attacks aluminum and copper, or non-ferrous materials. When the pH level is below 7.0, the coolant becomes acidic and attacks ferrous materials. When the pH level is below 7.0, or above 11.0, the coolant mixture is unsuitable. Least corrosion occurs between 8.5 and 10.0.

Temperature has an effect on pH level. At higher temperatures, pH is generally lower.



pH scale for coolant mixture

Supplemental coolant additives used in the coolant mixture must contain buffering agents to properly maintain the pH level and to neutralize acids produced by blow-by gases.

Galvanic and Electrolytic Corrosion

Electrical current flowing through coolant between different metals causes galvanic corrosion. The coolant acts as an electrical conductor between metals that are coupled together. An electromotive force or a potential voltage that exists between the two dissimilar metals allows current to flow. Galvanic corrosion occurs on the least resistant metal.

In marine applications where sea water is highly conductive, sacrificial material (rods) are placed in seawater flow passages to absorb current flow. Typically, this wear material is either magnesium or zinc. Rods must be inspected regularly and replaced when necessary. Caterpillar recommends inspecting rods every 50 hours until a wear rate is established.

In truck, earthmoving and other non-marine applications, if galvanic corrosion occurs, immediately drain, flush and refill the coolant mixture. The source of voltage must be determined to prevent continued corrosion.

Corrosion can also occur when the source of current flow through the coolant is external. To help prevent this electrolytic corrosion, electrical systems must be designed so that no continuous electrical potential is imposed upon any cooling system components. Despite coolant mixture quality, the presence of an electrical potential can cause materials in the cooling system to be damaged by electrolytic corrosion. Soundness of ground connections should be checked with a volt/ohm meter. Typically, measured resistance between an electrical component on the engine and battery negative should be less than 0.3 ohms. All grounds should be tight and free of corrosion.

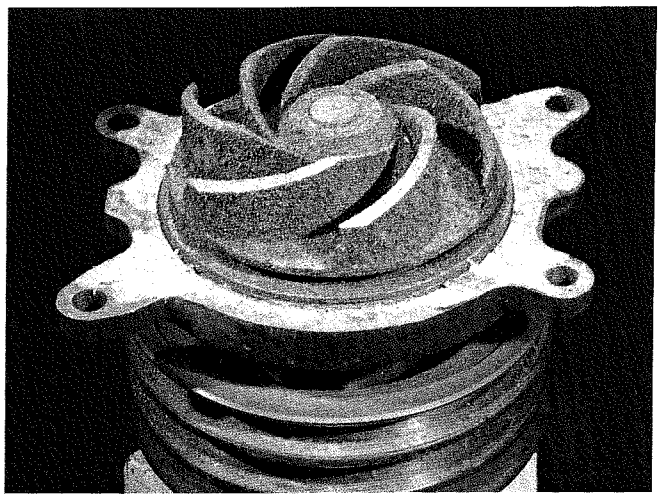
Aluminum material parts are susceptible to electrolytic corrosion. Aluminum requires only about one-half the electrical potential as iron to produce the same damaging effect. With the aluminum components of newer engines, greater care is required to ensure proper grounding to prevent electrical potential differences.

Troubleshooting these types of corrosion is extremely complicated. The source of electrical current must be located. Common sources of problems are improper grounding of electrical components or corroded ground strap connections.

Scale and Deposit Formation

The general characteristics of water – including pH level, calcium and magnesium hardness, total hardness and temperature – determine scale and deposit formation. Use of supplemental coolant additive is a major factor in scale and deposit formation. Common scale deposits in a cooling system include:

- calcium carbonate
- calcium sulfate
- iron
- copper
- silica
- lead.



Rust deposits on water pump impeller caused by lack of supplemental coolant additive

Scale and deposit formations are detrimental to the cooling system because they act as insulators and barriers to heat transfer. Thus, scale and deposit formations reduce the cooling system's efficiency. Only 1.6 mm (1/16″) of scale has the same insulating potential as approximately 101 mm (4″) of cast iron. This thin scale deposit can reduce heat transfer by 40%. In many cases, severe damage to the engine results.

It is impossible to completely eliminate poor water characteristics. However, water must be pretreated to meet the manufacturer's specifications for the cooling system. (See page 8).

Used in proper concentration, Caterpillar's supplemental coolant additive helps prevent the formation of scale and deposits.

Aeration

Air leakage into the cooling system often results in coolant foaming. Foaming promotes pitting, particularly around water pump impellers. Pitting and corrosion increase significantly when exhaust gases enter the cooling system, introducing bubbles and foam.

To help prevent such problems, foam suppressant additives must be added to the coolant mixture. Caterpillar's supplemental coolant additive contains de-foaming agents and helps prevent air bubble formation.

Coolant-Related Failures

Because of the cooling system's vital function in regulating temperature, coolant-related problems such as corrosion or aeration in the cooling system can ultimately lead to failure of the engine. Temperatures that are excessively high or low lead to engine failure. Overheating typically causes cracking of cylinder heads and cylinder blocks, and seizure of pistons. Excessively low operating temperatures lead to other types of problems, such as sludge formation and carbon build-up.

Overheating can be traced to many different sources:

- low coolant level
- plugged radiator core
- broken or leaking coolant hoses
- loose fan belts
- excessive engine load
- failure of water pump or water temperature regulator
- restriction of inlet or exhaust air flow
- engine operation with no temperature regulator
- cooling system (heat exchanger, cooler or radiator) that is defective or too small.

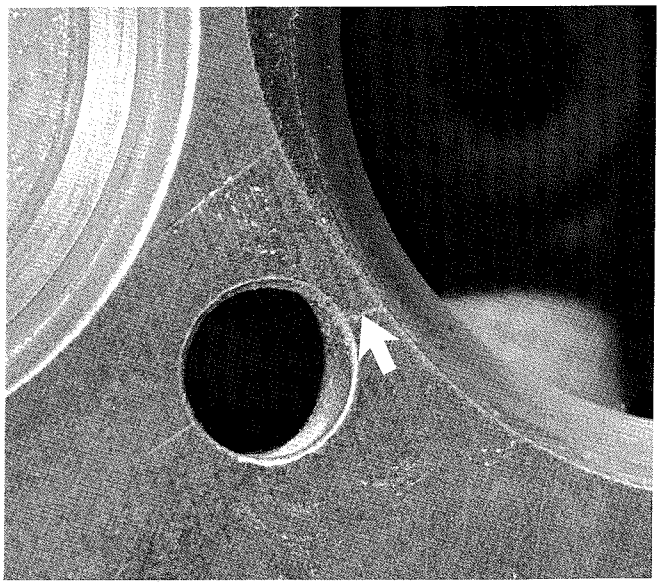
Many of these causes are related to coolant. Examples of coolant-related failure symptoms are cracked or warped cylinder heads, cylinder block damage, piston seizure and cold operating temperatures.

Cracked or Warped Cylinder Heads

When an engine overheats, stress in the cylinder head increases. This can cause the cylinder head to become warped or cracked.



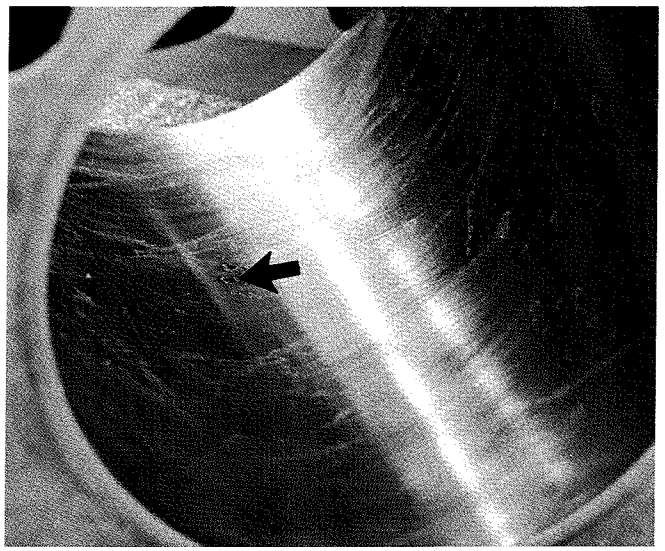
Coolant-related overheating caused this crack in the cylinder head at the nozzle hole.



Further inspection of the crack shows extension into the valve seat area.

Cylinder Block

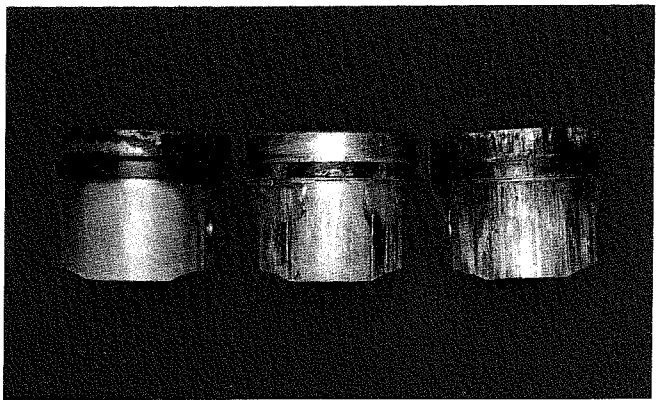
The cylinder block represents another potentially vulnerable area. Cavitation erosion and excessive pitting in the water passage around the cylinder can cause holes in the cylinder wall. Pitting and cavitation-erosion often result from incorrect cooling system maintenance, and can help be prevented by regularly using and replenishing the cooling system with Caterpillar's supplemental coolant additive.



Holes in cylinder wall on a 3208 engine block caused by cavitation erosion and pitting

Piston Seizure

Piston damage in varying amounts is also typical of overheating failure. Normally, several pistons have seizure damage (scuffing), while the skirts of the remaining pistons are polished or have normal appearance. Usually, more severe damage occurs on pistons in one or more of the rear cylinders.



Piston damage on this direct-injection engine resulted from improper cylinder jacket cooling. As shown by the middle piston, seizure usually begins in the skirt area while the top land escapes damage. The piston on the right shows further progression after skirt seizure

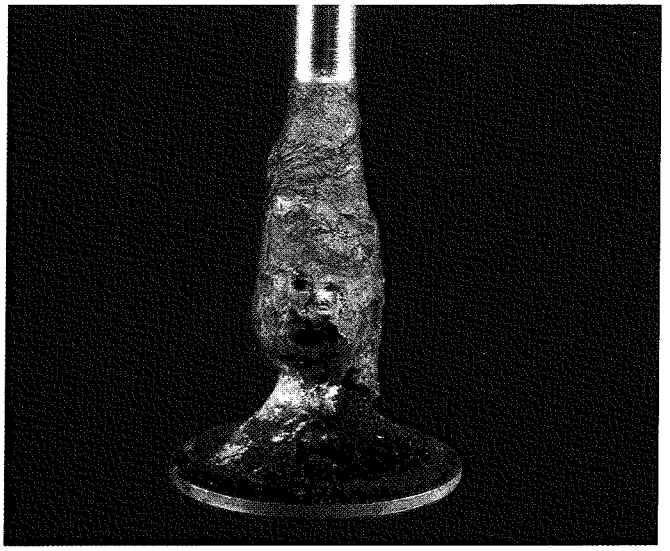
Seizure damage from improper cylinder jacket cooling usually begins in the piston's skirt area on direct injected fuel system engines. On precombustion fuel system engines, piston seizure often begins at the top land.

Cold Operating Temperatures

Overcooling can damage an engine in the same way overheating can. Correct operating temperature is critical to engine performance. Engines must reach a specific operating temperature to run efficiently and prevent failures.

Continued engine operation at cold temperatures can result in sludge formation in the crankcase. Sludge can gum valve lifters and stems, and pistons and piston rings. Also, when using fuels with high sulfur content, sulfuric acid can form more readily and accelerate corrosion.

Cold operating temperatures can also lead to carbon buildup. Carbon buildup is a result of over-lubrication or cold engine operation. Correct temperatures help reduce carbon deposits from forming on valves.



Excessive carbon buildup on an intake valve Carbon buildup can be caused by engine operating at cold temperatures

All Caterpillar Engines are equipped with temperature regulators (thermostats) for temperature regulation. Regulators can vary according to engine application. Make sure the recommended regulator has been installed and is operating correctly.

Cooling System Cleaners

Before Caterpillar's supplemental coolant additive can be effective, the cooling system must be free from rust, scale and other deposits. Preventive cleaning helps avoid downtime caused by expensive out-of-service cleaning required for extremely dirty and neglected cooling systems.

Caterpillar Cooling System Cleaners:

- Dissolve or depress mineral scale, corrosion products, light oil contamination, and sludge.
- Clean engine while still in service.
- Reduce downtime and cleaning costs.
- Avoid costly repairs from pitting and other internal problems caused by improper cooling system maintenance.
- Can be used with glycol-based antifreeze.

Caterpillar Cooling System Cleaners are designed to clean the system of harmful scale and corrosion without taking the engine out of service. The cleaners can be used in all Caterpillar Engines' and other manufacturers' cooling systems in any application. This mild solvent must *not* be used in systems that have been neglected or have heavy scale buildup. These systems require a stronger commercial solvent available from local distributors.

For most effective results, add 1.9 liters (.5 gallon) of system cleaner for each 30.3 liters (8 gallons) of cooling system capacity. Follow label directions for proper usage.

Periodic Maintenance

Periodic maintenance is necessary for the cooling system to operate efficiently. The following maintenance practices extend both cooling system and engine service life.

NOTE: These are general recommendations. For specific requirements, consult the engine manufacturer's owner's guide.

⚠ WARNING

To avoid burns, inspect only when coolant temperature is low.

INITIAL FILL

1. Select proper water, supplemental coolant additive, and antifreeze.
2. Before the cooling system is filled, close all drain plugs.
3. Before adding to the cooling system, always premix water, supplemental coolant additive, and antifreeze mixtures.
4. Do not fill the cooling system faster than 19 liters (5 gallons) per minute. This prevents air pockets from developing. Air pockets result in an incomplete fill and could possibly cause damaging steam.
5. After filling the cooling system, run the engine for several minutes with the radiator cap off. Next, install the radiator cap and run the engine at low idle until the coolant becomes warm.
6. Inspect coolant level in top tank. If necessary, add coolant and install radiator cap. Examine all cooling system components for leaks. If none are found, the engine is ready for service.

10-HOUR OR DAILY CHECK

1. Inspect the coolant level in the top tank.
2. Remove foreign material and dirt from outside the radiator core (and between the panels of folded core radiators).

50-HOUR INTERVAL

1. Perform all 10-hour maintenance.
2. Inspect zinc or magnesium rods if so equipped.

250-HOUR OR MONTHLY CHECK

1. Perform all 10 and 50-hour maintenance.
2. Inspect the condition and tension of all fan belts. If necessary, adjust or replace any belts.
3. Add supplemental coolant additive, or change element assemblies if so equipped.
4. Test the coolant for freeze protection.
5. Inspect the radiator cap gasket.
6. Inspect all hoses for leaks.
7. Inspect/check all engine grounds.

3000 HOURS OR 24 MONTHS (whichever occurs first)

1. Perform all 10, 50 and 250-hour maintenance.
2. Drain, clean and refill the cooling system. (See page 28, Caterpillar Cooling System Cleaners.)
3. Inspect the condition of fan blades and guards. Inspect the condition of hoses and clamps. Tighten all clamps.
4. Obtain a coolant analysis.

Troubleshooting Checklist

Three basic problems are typical of cooling systems:

- overheating
- overcooling
- loss of coolant.

A cooling system problem should first be diagnosed by visual inspection. If the problem cannot be diagnosed, tools must be used to find the cause.

Caterpillar has published a booklet entitled "Know Your Cooling System" (see page 31) that contains the following service information in extensive detail:

- Cooling system inspection, test and troubleshooting procedures
- Overheating and overcooling problems and causes
- Steps to clean and recondition cooling systems
- Components that affect cooling systems
- Troubleshooting test equipment.

Cooling System Maintenance Products

Supplemental Coolant Additive

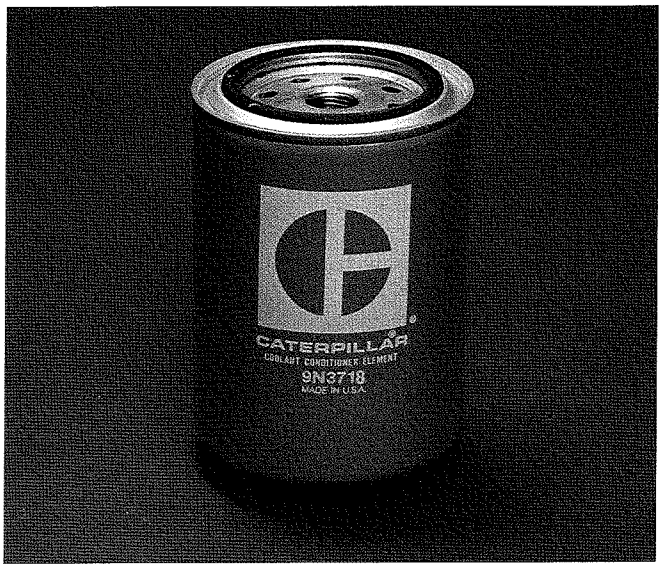


Caterpillar supplemental coolant additive

Supplemental coolant additive helps prevent rust, mineral and deposit formation in the cooling system. It helps protect all metals, including aluminum. It does not affect gaskets or hoses. It is compatible with glycol-base antifreeze and has no adverse effect on lubricating oil.

See page 10 for available quantities and part numbers.

Supplemental Coolant Additive Elements



Supplemental Coolant Additive Element

Spin-on supplemental coolant additive elements contain a pre-measured amount of chemical coolant additives that dissolve during engine operation. It can be used year-round to help prevent cavitation, corrosion and erosion. Elements are available for all diesel engines. To avoid over-concentration, never use supplemental coolant additive elements and supplemental coolant additive simultaneously.

See page 11 for available quantities and part numbers.

Antifreeze



Caterpillar Antifreeze

Caterpillar Antifreeze is specially formulated for use in diesel cooling systems. It helps protect against cylinder liner and block pitting and helps prevent corrosion. It does not require supplemental coolant additive at initial fill.

See page 14 for available quantities and part numbers.

Cooling System Cleaners



Caterpillar Cooling System Cleaners

Caterpillar Cooling System Cleaners are designed to clean the system of harmful scale and corrosion without taking the engine out of service. It can be used in all Caterpillar Engines' and other manufacturers' cooling systems in any application. This mild solvent must *not* be used in systems that have been neglected or have heavy scale buildup. These systems require a stronger commercial solvent available from local distributors.

Caterpillar's Cooling System Cleaners are available (Part No.6V4511) in 1/2 gallon (1.9 liters) containers or, if an immediate cleaning is desired, the following Caterpillar Cooling System Cleaners can be used:

4C4609	1 pint
4C4610	1 quart
4C4611	1 gallon
4C4612	5 gallon
4C4613	55 gallon

Drain the cooling system completely. Refill with clean water and a 6% to 10% concentration of cleaner. Run the engine for 1 1/2 hours. Then, drain the coolant and flush the system completely with clean water. Refill the system with the proper amount of antifreeze and the appropriate supplemental coolant additive concentration.

NOTICE

Use of commercially available cooling system cleaners may cause damage to the aluminum components in the cooling system. Use only cleaners that are approved for use with aluminum. *DO NOT* use a Trisodium Phosphate based cleaner, it *WILL* damage aluminum.

Supplemental Coolant Additive Test Kit (8T5296)

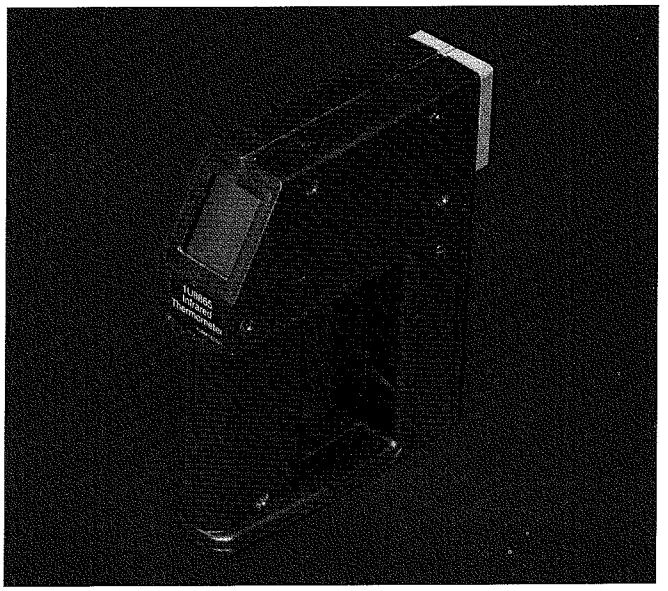


Caterpillar's supplemental coolant additive test kit

This simple, inexpensive test kit accurately measures the concentration of Caterpillar supplemental coolant additive and the ethylene glycol range in your coolant mixture. It helps protect against insufficient or excessive concentrations which can damage your engine. The test takes only minutes to perform.

NOTE: The Caterpillar supplemental coolant additive Test Kit checks for the concentration of nitrites in the coolant. Some other brands of supplemental coolant additives are phosphate based, and the test kit will yield inaccurate readings. If another supplemental coolant additive is used, Caterpillar recommends using that manufacturer's test.

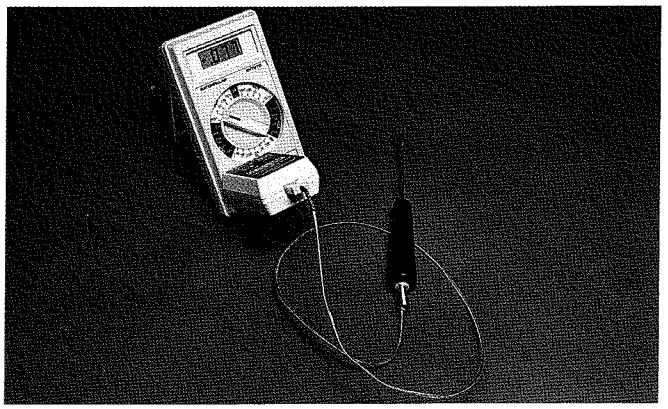
Infrared Thermometer (1U8865)



Infrared thermometer

This portable non-contact microprocessor-based thermometer is rugged and easy to operate. It is ideal for determining the temperature of objects that are out of reach, too hot to touch or continuously moving. Measurement Range: –18° to 871°C (0° to 1600°F).

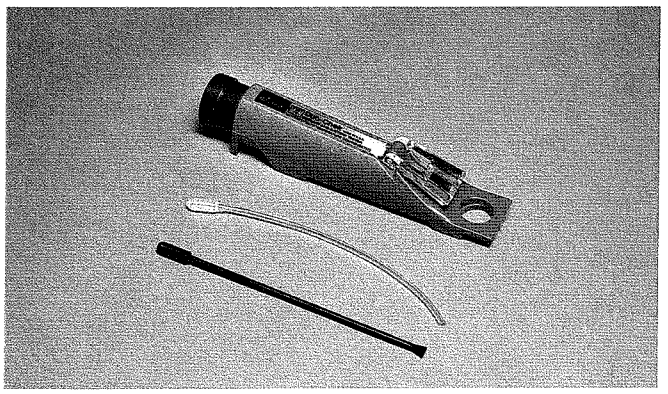
Thermocouple Temperature Adapter (6V9130)



Thermocouple temperature adapter

For use with most digital multimeters. Ranges from -46° to 900°C (-50° to 1,652°F). Probes available include a hand probe, wire, immersion and exhaust probe.

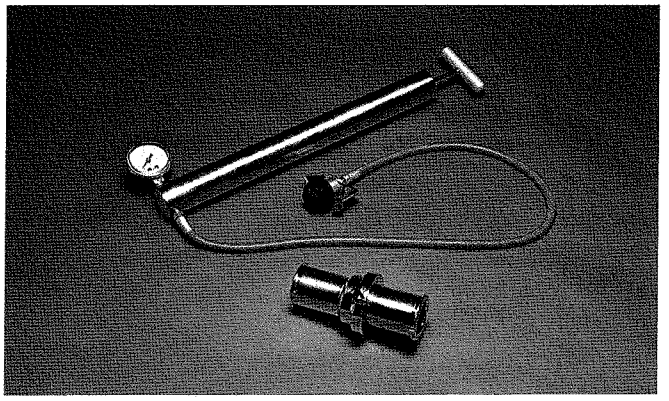
Coolant and Battery Testers (5P0957, 5P3514)



Caterpillar coolant and battery tester

Both testers give a rapid and accurate reading for checking coolant freezing temperature and battery fluid condition. They can be used for coolants using ethylene glycol or propylene glycol type antifreezes. Only a few drops are necessary to make the test. They can be used for either hot or cold radiators. Both testers are identical except temperature scale on 5P0957 Tester reads in degrees Fahrenheit, and 5P3514 reads in degrees Celsius.

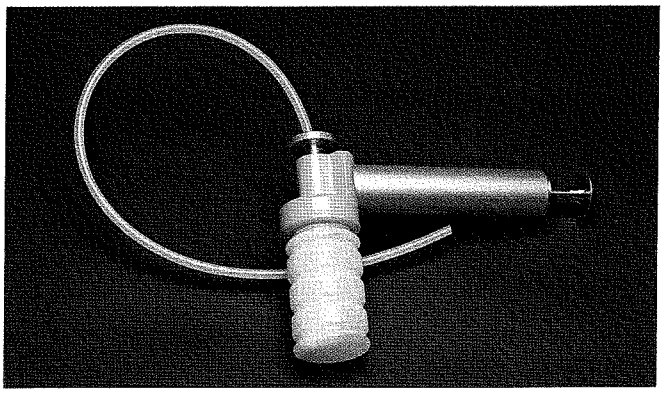
System Pressurizing Pump (9S8140)



Caterpillar system pressurizing pump

The system pressurizing pump puts pressure into the cooling system to test the pressure relief valve and pressure gauges.

Fluid Sampling Extraction Pump (1U5718)



Caterpillar fluid sampling extraction pump with sample bottle

The fluid sampling extraction pump is designed for obtaining fluid samples, including engine coolant samples, from non-pressurized compartments. This tool can also obtain fluids from pressurized compartments when a machine is not operating.

Accessories available include a pump repair kit, sample bottle, mailing container, tube cutter, blade, and suction tube.

Summary

Cooling system maintenance is your responsibility. Extra time invested in caring for your cooling system can prolong engine life and lower operating costs.

The consequences of improper coolant selection and cooling system maintenance are evident. Coolant-related failures and loss of efficiency directly affect your operation.

Selecting and maintaining the proper coolant helps your engine in the long run. Understanding coolant and its effects on your engine is crucial to an efficient operation.

Publications Available From Caterpillar

The following publications are available through your local Caterpillar dealer. Some publications may have a nominal charge.

Know Your Cooling System
SEBD0518

Dowtherm 209 Full-Fill Coolant
LEKQ6333 (Engine Data Sheet 55.1)

Cold Weather Recommendations
SEBU5898

Marine Engines Application and Installation Guide
LEBM2239

Cooling System Fundamentals
LEKQ1476

Installation of Coolant Conditioner Group
SEHS7222

Oil And Your Engine
SEBD0640

Diesel Fuels And Your Engine
SEBD0717

Periodically, cooling system articles are included in Caterpillar® Engine News and Truck Engine News, and Caterpillar® Special Instructions. These publications are also available through your local Caterpillar® dealer.

"Engine Data Sheets" are included in the Caterpillar® "Engine Technical Manual," Form LE000002 (Volume 1).

Other Publications

Standards Methods for the Examination of Water and Wastewater, 14th ed.
American Public Health Association
1015, 18th Street NW
Washington, D.C. 20036

1981 Annual Book of ASTM Standards Part 31
American Society for Testing and Materials
655 15th St. NW
Washington, D.C. 20005

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