PENRAY®

TECHFACTS

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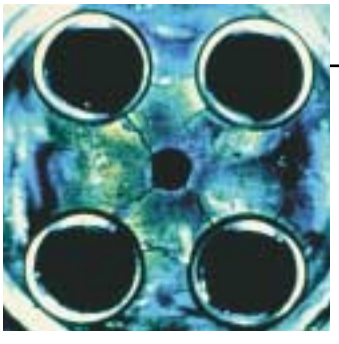
Common Cooling System Problems

Cavitation - Erosion

Corrosion



Scale Deposits

Fill-For-Life® from Penray is the Answer

Understanding Cooling Systems

Industry experts estimate that about 40% of engine downtime is caused by cooling system problems. Understanding the common problems and implementing proven preventative maintenance practices significantly reduces their operating costs. Cooling system engineers have specific terms that they use to discuss cooling systems, their components, and system maintenance. Some of these terms are listed in the Glossary to the right.

The four major problems relating to cooling systems are:

- Corrosion
- Cavitation-erosion
- Scale deposits
- Green-goo or drop-out

Cavitation - Erosion

Cavitation in Cooling Systems

One of the most common and costly results of improper cooling system maintenance is the perforation of wet-sleeve cylinder liners. The perforation is caused by repetitive pitting of the liner resulting from liner vibration. As the fuel inside ignites, the liner vibrates within the block. The outside wall of the liner actually moves away from the coolant causing a near vacuum for an instant. This low-pressure causes the surrounding coolant to boil, forming tiny bubbles. The liner then returns to its position at extremely high velocity, pressing against the bubbles with a violent force. The bubbles implode (collapse) against the liner wall surface at pressures up to 60,000 PSI! The collapse of these bubbles blasts small holes in the cast iron liner. This pitting process will repeat, digging tiny tunnels through the liner **(Figure 1)**. Eventually, the liner wall will become perforated, allowing coolant to enter the combustion side of the cylinder.

Figure 1
A cylinder liner destroyed by cavitation-erosion.

If coolant enters the combustion side of the cylinder, an expensive in-frame overhaul is required. Liquid coolant does not compress when a piston fires with coolant in the combustion chamber. It can be blocked by the coolant, preventing it from making an entire stroke. This usually results in a bent rod and can cause a cracked block. Secondly, coolant can leak down into the engine oil. This results in overheating of lubricated moving parts and can destroy an engine. "Fully-formulated" coolant contains nitrite. Nitrite will form a thin protective oxide film on the coolant side of the liner wall. This oxide film, which is formed by reaction of the nitrite with the liner wall, acts as a protective barrier to prevent corrosion and cavitation erosion (pitting) from occurring.

In a properly protected system that contains Pencool®, the imploding bubbles attack the protective film. The film quickly repairs itself by drawing nitrite from the coolant. In an improperly protected system, the bare metal surface remains unprotected and pitting occurs.

Engine Conditions that affect Liner Pitting

An increase in air bubbles in a cooling system can increase the potential for cavitation erosion (pitting) of metal surfaces. Increased air can enter the cooling system through cooling system leaks and/or a faulty radiator cap. This reduces cooling system pressure and increases the potential for bubble formation in your coolant.

The potential for liner pitting increases in cold weather. When an engine is cold, engine vibration increases because of increased piston-to-cylinder clearance and because the engine has a tendency to lug in cold weather.

Engines that support loads that fluctuate rapidly, such as in school and transit buses, fire trucks, or garbage trucks, experience more vibrations. These types of engines experience a high incidence of liner pitting.

Cooling system maintenance

Cavitation-erosion is not usually covered under engine warranties. Major engine manufacturers recommend the use of supplemental coolant additives, like Pencool. Penray recommends that Pencool be added to an engine's cooling system by using a Need-Release® filter. Some users may prefer to use Pencool liquids or filters.

The corrosion inhibitor you select will have a major impact on your maintenance costs and the profitability of your operation. Pencool will give you the competitive edge you need to keep your maintenance costs down and keep your engines generating profits rather than repair bills.

Coolant Terminology

Antifreeze: Pure glycol (typically 95%) with an inhibitor package added. Antifreeze cannot be used by itself, it must be mixed with water before being put into the engine's cooling system.

Azole: These chemicals provide copper and brass protection. The most common are MBT (Mercaptobenzothiazole) and TT (or TTZ) (Tolyltriazole).

Borate: A very soluble pH buffer used in premium antifreezes.

Coolant: Antifreeze mixed with water, (or water mixed with an additive package for use in warm climates).

Conventional Coolant: Ethylene glycol that contains a corrosion inhibitor package consisting of inorganic inhibitors such as silicate, phosphate, nitrite, nitrate, and azoles.

Fully-Formulated Antifreeze or Coolant: A modern product that contains all of the necessary inhibitors for both diesel and gasoline powered engines. (TMC RP-329 or TMC RP-330 specifications).

Ethylene Glycol: The most common base used in the manufacturing of antifreeze.

Nitrite: The primary inhibitor for wet sleeve liner pitting protection. It also protects against rust.

Nitrate: A corrosion inhibitor that provides solder and aluminum protection.

pH: A measure of the alkalinity of the coolant.

Reserve Alkalinity: A measurement of the amount of acid required to reduce the pH of coolant to 5.5. A quality control tool.

Phosphate: An inexpensive pH buffer. Phosphate is used in some antifreeze brands. It is not permitted in coolant used to protect Mercedes, BMW, Volkswagen, MTU or Detroit Diesel engines.

Propylene Glycol: A less toxic, but more costly, alternative to Ethylene Glycol.

Silicate: The primary conventional inhibitor for aluminum. In heavy duty coolants, lower (less than 250 ppm) silicate concentrations are preferred.

Corrosion

Corrosion is the natural tendency of metals to revert back to their ore form. Cast iron, for example, will form reddish-brown iron oxide (common rust) on engine surfaces **(Figure 2)**. Likewise, other metals form oxides. The color of these various corrosion products can vary from white to black depending on the specific oxide that is formed.

A number of conditions in a cooling system will affect the degree and rate at which metal surfaces corrode. These include: coolant pH, the concentration of dissolved oxygen and carbon dioxide in a coolant, metal surface deposits, metal stress, coolant temperature, acids formed in the combustion process of the fuel, and the corrosion inhibitors present.

All the metals in a cooling system will corrode under certain conditions. Some metals are more sensitive than others. When metals corrode they weaken and the component will eventually fail. The metal most prone to corrosion in a cooling system environment is aluminum **(see Figure 2, bottom)**. Cast iron, solder, steel, copper, and brass will also corrode.

Coolant pH

One major factor on the corrosion rate of the metals is the coolant's pH. Shifts in coolant pH will affect the metals that corrode and the rate of each metal's corrosion. The pH scale runs from 0 to 14. A coolant becomes more acidic closer to zero; and more alkaline toward 14. Coolant pH should always be maintained between 8.5 and 11. If a coolant's pH drops below 8.5, it will become aggressive to ferrous metals (cast iron and steel), aluminum, copper and brass. If it increases above 11, it will become aggressive to aluminum and solder in a cooling system. Maintaining optimum pH in a coolant is a critical function of a quality coolant additive (SCA). It is important to use a coolant additive package containing a pH buffer to insure the optimum pH range of the coolant.

A good corrosion inhibitor should contain the following critical components for proper corrosion protection:

pH buffer. This will help maintain optimum coolant pH (8.5 to 11). Borate, for example, is one of the best pH buffers available. It helps hold a coolant's pH within the optimum range for providing corrosion protection for iron and steel components.

Silicate. This is the best corrosion inhibitor for protecting aluminum metal surfaces.

Nitrite. Nitrite provides the best protection available for cavitation-erosion (liner pitting).

Tolytriazole (TT) and Mercaptobenzothiazole (MBT). These inhibitors provide protection for copper and brass.

Phosphate, Borate, and Nitrate – provide aluminum and ferrous metals protection (iron and steel).

Summary

A modern coolant that meets TMC RP-329 or RP-330 will provide excellent protection for essentially any engine cooling system. This is the simplest solution to corrosion problems.

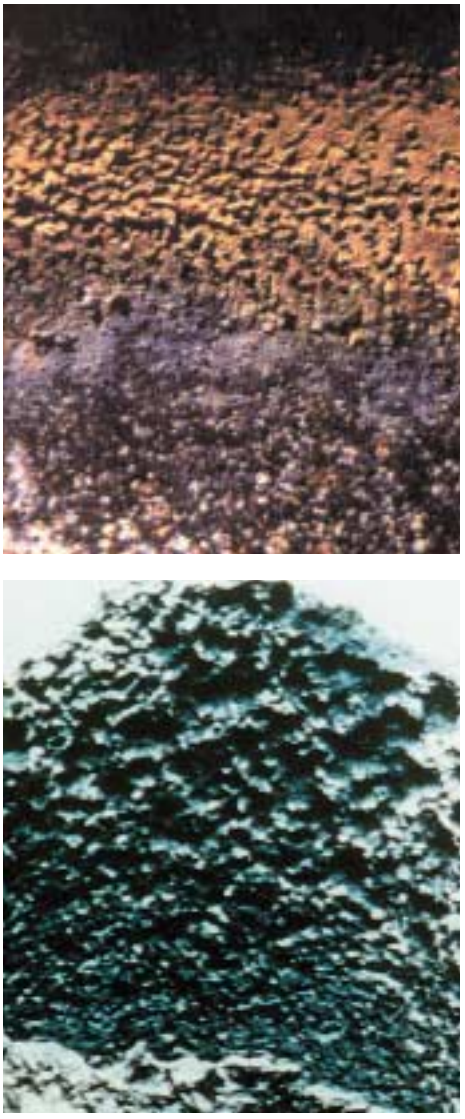


Figure 2
Rust on iron (top) and aluminum corrosion (bottom) in a cooling system.

Scale

A diesel engine generates enough heat to warm a seven-room house during the winter. The engine must shed some of this heat to operate efficiently and prevent severe component damage. Two-thirds of this heat is lost through the exhaust and through the engine work. The remaining third must be pulled from an engine by the cooling system.

It is critical that all cooling system heat exchange surfaces remain clean **(Figure 3)**. Hard water scale can block a cooling system's ability to transfer heat, resulting in overheating. Only 1/16 inch of scale will reduce cooling system heat transfer efficiency by 40%!

Calcium and Magnesium

Most cooling system water contains calcium and/or magnesium. Water that contains over 170 ppm of these minerals is considered "hard-water". It is wonderful to drink, but these minerals can form scale in engine cooling systems. As the concentration of these minerals increases, so does the probability that you will have cooling system scale problems. The level of dissolved solids in coolant water is generally referred to as the "total hardness" reported in parts per million (ppm). Cooling system additives that contain anti-scale chemicals can allow the use of moderately hard water. It is best to use water that is at least as good as the recommended water quality listed in the ASTM standards D-4985.

(continued on page 4)

Scale (continued from page 3)

How Scale Forms

The potential for scale formation on hot metal cooling system surfaces is affected by a number of dynamic conditions. Some of the mechanisms and parameters that affect the formation of these deposits:

- **Water hardness** – the harder the water being used in an engine coolant, the greater the potential for scale formation.
- **Temperature** – as coolant temperatures increase, hardness salts (calcium and magnesium) in solution have the potential to plate out on hot metal cooling system surfaces.
- **Flow characteristics** – scale generally forms on the hot side of a cooling system and in areas of low or turbulent flow.
- **Entrapped air** – any air bubble formation in a coolant area (bubbling around a hot source) increases the tendency for scale to form in that area.
- **pH** – high pH will increase the potential for scale deposits.

Damage to water pump seals.

Calcium and magnesium have the tendency to combine with the phosphates found in old-fashioned antifreeze and some additive packages. They form calcium and magnesium phosphate scale on heat transfer surfaces, especially on water pump seal faces. These deposits can distort the flatness of a seal face, preventing the water pump seal from sealing. The result can be leaking water pumps.

Cooling system problems that result from overheating caused by scale:

- Cracked heads and warped engine blocks.
- Oil temperature running abnormally high.
- Failure of the cooling system fan to turn on.
- Scale deposits on cooling system block heaters.

Controlling scale deposits in an engine cooling system.

Scale removal

Prior to initiation of a coolant maintenance program, the cooling system should be cleaned of all existing contamination and hard water scale deposits.

Off-line cleaners:

For cooling systems that contain a lot of oil and carbon, or systems that have not been cleaned for a long time, Penray recommends using Penray 2015 Twin Pac treatment. The Twin Pac product contains a very strong cleaner (Penray 2010) that removes heavy scale deposits and rust. After the cleaner has been used, a conditioning rinse (Penray 2011) is used to neutralize the cleaner and prepare the metal surfaces for new coolant.

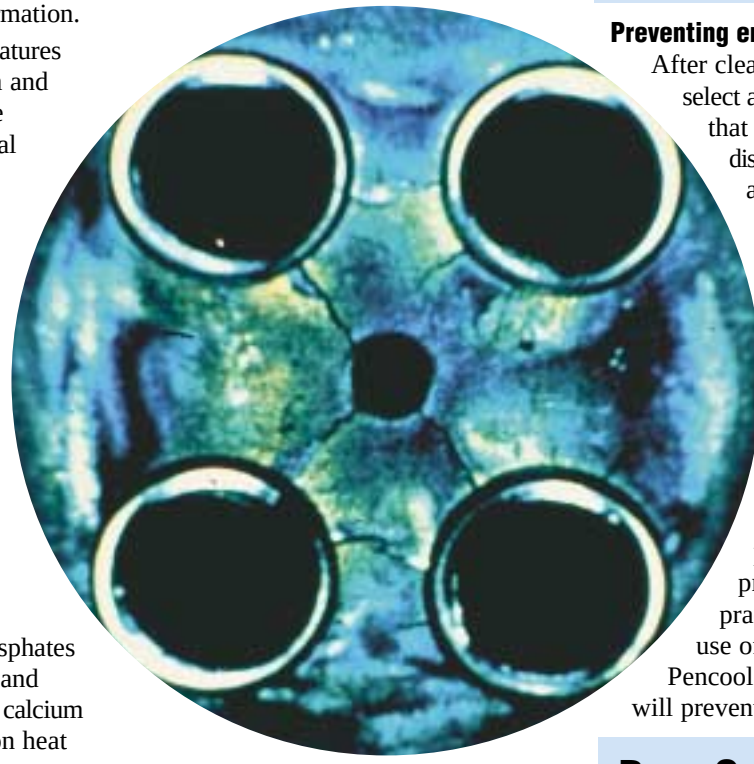


Figure 3
Scale ruined this head.

On-line cleaner:

Penray developed Penray 2001 treatment for on-line cooling system cleaning. This allows for cleaning of harmful mineral scale, rust and corrosion deposits from cooling system metal surfaces while the engine is in operation. Penray 2001 cleaner is an inhibited cleaner. It contains a well-balanced corrosion inhibitor package that provides total metal corrosion protection while it cleans. Clean your system when any of the following occurs:

- When you notice water pump leaks (leaking around the weephole).
- When your cooling system fan is not operating properly.
- When the cab or bunk heater is not getting any heat during winter months.
- When oil temperatures are running hot.
- When thermostats start sticking.
- Before changing the coolant.

ASTM Water Quality Suggestions

Total Solids	340 ppm max.
Total Hardness	170 ppm max.
Chloride	40 ppm max.
Sulfate	100 ppm max.
pH	5.5 – 9.0

Preventing engine scale:

After cleaning your cooling system, select a corrosion inhibitor package that contains a good scale dispersant. Penray has developed a scale dispersant for optimum antiscale effectiveness which is used throughout the entire Pencool line.

Summary:

Scale build up is serious and can destroy an engine. Pre-existing scale can be removed restoring optimum engine cooling system performance. Intelligent preventative maintenance practices, including the proper use of Penray products such as Pencool and Penray cleaners, will prevent scale from forming.

Drop Out or Green Goo

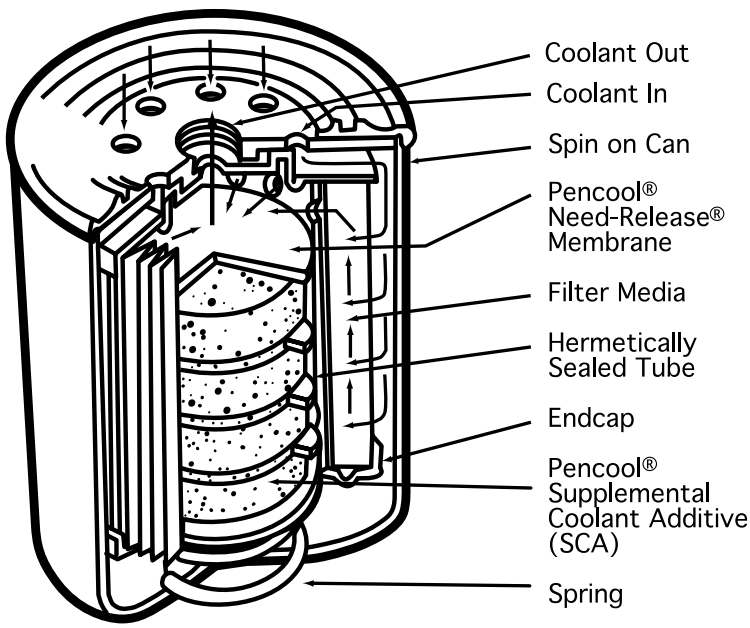
Many of today's antifreezes rely on the inhibitors silicate and phosphate. Although they serve as valuable corrosion inhibitors in engine coolant they have limited solubility. If antifreeze or additives get too concentrated in the coolant, the excess phosphate and/or silicate will drop out, forming green goo. This green goo can lead to premature water pump failure, radiator blockages, heater core problems, and extensive down time.

By using low-silicate, phosphate-free fully formulated antifreeze in your coolant, you can eliminate the potential for green goo formation. This antifreeze is standard factory fill in many OE engines and is also readily available in the marketplace. Further, Penray's Pencool® 3000 with Stabil-Aid® Cooling System Treatment helps prevent drop out caused by over treatment and incorrect antifreeze concentrations.

PENRAY Fill-For-Life®

Fill-For-Life® uses the Penray Need-Release® filter to provide automatic coolant maintenance for the life of your engine!

You will eliminate scheduled coolant changes! That is the promise of the Fill-For-Life® Extended Service Coolant program. The advanced technology in the Penray Need-Release® filter eliminates the need for scheduled coolant changes between engine overhauls. The Need-Release® filter automatically releases supplemental coolant additives (SCAs) as needed to provide superior protection against corrosion, liner pitting, and scale. Just change the Need-Release® filter every 15 months, 150,000 miles, or 3000 hours. Let Need-Release® help you keep your cool!



NEED-RELEASE® Filters

NF2088
Fits standard filter bracket for Detroit Diesel, Caterpillar, Cummins, Ford, etc. engines. Compatible with an 8-20 gallon cooling system capacity that has been pre-charged with 1200-1400 PPM nitrite.

NF20891
Fits Mack, Mid-Liner, Mack V-8, 65, and Econo-Dyne series engines. Compatible with an 8-20 gallon cooling system capacity that has been pre-charged with 1200-1400 PPM nitrite.

NFC2090
Fits Mack, ESI, E-9, and Maxi-Dyne engines. Compatible with an 8-20 gallon cooling system capacity that has been pre-charged with 1200-1400 PPM nitrite.

NF2091
Fits standard filter bracket for Detroit Diesel, Caterpillar, Cummins, Ford, etc. engines. Compatible with an 8 gallon or less cooling system capacity that has been pre-charged with 1200-1400 PPM nitrite.

NF2095
Fits Cummins ISX engines. Compatible with an 8-20 gallon cooling system capacity that has been pre-charged with 1200-1400 PPM nitrite.

Questions & Answers

Q. WHAT IS A Fill-For-Life® PROGRAM?

A. Fill-For-Life® is an extended service interval (ESI) coolant program for medium and heavy-duty trucks. The coolant's life is extended to correspond with the life of the engine by:

1. Filling the cooling system with engine coolant consisting of 50% phosphate-free, low-silicate antifreeze, meeting coolant specification TMC* RP-329 Type A for ethylene glycol, or RP-330 for propylene glycol and 50% water meeting the specification of ASTM D-4985.
2. Installing a Penray Need-Release® filter.

*TMC is an abbreviation for "Technology and Maintenance Council" of the American Trucking Associations, Alexandria, VA.

Q. WHO MAKES PHOSPHATE-FREE, LOW SILICATE, TMC RP-329 Type A SPECIFICATION ANTIFREEZE?

A. Many heavy-duty parts suppliers carry this antifreeze. Below are some of the name brands.

- Caterpillar® Heavy-Duty Antifreeze/Coolant
- Detroit Diesel PowerCool®
- MacGuard® Antifreeze/Coolant
- Old World Industries Fleetcharge™
- Prestone® Heavy-Duty Antifreeze/Coolant
- Sierra® Fleet (TMC RP-330 specification, this is a propylene glycol based product.)

Several high quality recycling services who use reverse osmosis, distillation or ion exchange to strip the old coolant of contaminants, and then add advanced Penray inhibitor chemistry provide a recycled coolant that meets TMC RP-329 Type A..

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Questions & Answers (continued from page 5)

Q. WHERE CAN I BUY A PENRAY Need-Release® FILTER?

A. From any of 80 independent Penray Power Fleet Warehouse Distributors or from these national OEM distribution sources:

- Detroit Diesel distributors and dealers
- Freightliner dealers
- Kenworth dealers
- Navistar dealers
- Peterbilt dealers

Q. WHAT BENEFITS DO THE Fill-For-Life® PROGRAM PROVIDE?

A. There are several important benefits:

1. Most of the standard factory-fill antifreezes in today's trucks meet the TMC RP-329 Type A specifications, so you don't have to change your new coolant or pay extra for a factory option.
2. Your program will be compatible with all TMC RP-329 Type A, RP-330, and organic acid type antifreezes, so you can use the new antifreeze in your older trucks, or buy antifreeze on the road in a pinch, without creating a cooling system catastrophe or voiding the Fill-For-Life® coolant warranty.
3. If your system becomes diluted or contaminated, you can fix it with your RP-329 Type A antifreeze and/or Pencool®3000. You don't have to throw the contaminated coolant away, and you do not lose the extended service benefit.
4. You can test your system easily with Penray 2-Way Test Strips or an inexpensive laboratory analysis to be sure it is in good shape.

Q. HOW DO I GET STARTED?

A. Follow these steps:

Note: If you have a new truck from Peterbilt, Kenworth, Freightliner, Volvo, Mack, Western Star or Sterling, skip to Part "B."

A. Drain and flush your system.

1. Open the stopcock and drain the coolant from the engine. Catch the old coolant and recycle* or dispose of it properly.
2. Flush the system with tap water until it runs clear, making sure to comply with local, state, and federal waste water regulations.
3. Allow the flush water to drain completely from the engine.
4. Close the stopcock.
5. Fill your system with a Fill-For-Life® approved coolant consisting of 50% phosphate-free, low-silicate TMC RP-329 Type A or RP-330 specification antifreeze and 50% water meeting the specification of ASTM D-4985.
6. Run the engine for 15 minutes to open the thermostat and circulate the coolant.
7. Proceed to Part "B".

*Reverse osmosis, distillation or ion exchange are the only acceptable recycling methods for this program.

B. For new truck application use a Penray 2-way coolant test strip, verify that the system contains 1200 - 1400 parts per million of nitrite and has a freeze point of -34 degrees F (-37 degrees C). Then:

1. Install a Penray NF2088 Need-Release® filter if your cooling system capacity is 8 to 20 gallons, or an NF2091 if your cooling system is 8 gallons or less.
2. Check your system at least every six months to determine if the cooling system has been invaded. Correct the coolant chemistry as recommended.
3. Replace the Need-Release® filter every 150,000 miles, 3,000 hours, or 15 months, whichever comes first.

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