DETROIT DIESEL

Cooling System Technician's Guide

Inspection/Analysis/Troubleshooting

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NOTE:

This Technician's Guide is intended for use by a technician who is skilled in diagnosis and repair of the cooling system. Contact an authorized Detroit Diesel service outlet for further information or clarification, if required. The information contained in this Technician's Guide may not be complete and is subject to change without notice.

WORK SAFELY

CAUTION:

The service procedures recommended by Detroit Diesel Corporation and described in this Technician's Guide are effective methods of performing service and repairs. Some of these procedures require the use of tools specially designed for this purpose.

Accordingly, anyone who intends to use a replacement part, service procedure or tool which is not recommended by Detroit Diesel Corporation must first determine that neither their safety nor the safe operation of the engine will be jeopardized by the replacement part, service procedure or tool selected.

This Technician's Guide contains various work procedures that must be carefully observed in order to reduce the risk of personal injury during service or repair or the possibility that improper service or repair may damage the engine or render it unsafe. It is also important to understand that these work procedures are not exhaustive, because it is impossible for Detroit Diesel Corporation to warn of all the possible hazardous consequences that might result from failure to follow these instructions.

A service technician can be severely injured if caught in the pulleys, belts or rotating parts of an engine that is accidentally started. To avoid personal injury, take this precaution before starting to work on an engine:

Disconnect the battery from the starting system by removing one or both of the battery cables (disconnect negative [ground] cable first). With the electrical circuit disrupted, accidental contact with the starter button will not produce an engine start. Also disable any air starting device.

SOME SAFETY PRECAUTIONS TO OBSERVE WHEN WORKING ON THE ENGINE

1.Consider the hazards of the job and wear protective gear such as safety glasses, safety shoes, hard hats, hearing protection, etc. to provide adequate protection.

2.When lifting an engine, make sure the lifting device is fastened securely. Be sure the item to be lifted does not exceed the capacity of the lifting device.

3.The front engine lifter bracket is not designed to lift more than the basic engine. When lifting with transmission attached, the proper hook points on the engine cradle or mounting rail *must* be used. Do not use the front lifter bracket alone under these circumstances. Failure to observe this precaution can result in personal injury and/or serious damage.

4.Always use caution when working with power tools.

5.When using compressed air to clean a component, such as flushing a radiator or cleaning an air cleaner element, use a safe amount of air. Recommendations regarding the use of air are indicated throughout the manual. Too much air can rupture or in some other way damage a component and create a hazardous situation that can lead to personal injury. Always wear adequate eye protection (safety glasses, safety face shield) when working with compressed air.

6.To avoid possible personal injury when working with chemicals, steam and/or hot water, wear adequate protective clothing (face shield, rubber apron, gloves, boots, etc.) work in a well ventilated area, and exercise caution.

7.Avoid the use of methylene chloride, carbon tetrachloride, carbon disulfide, trichloroethylene and perchloroethylene 1.1.1-trichloroethane as cleaning agents because they release harmful vapors. Use Tech Solv 340, which is less toxic and may be suitable for use as a cleaning agent. Use it with caution and always read and abide by the Material Safety Data Sheet (MSDS). Be sure the work area is adequately ventilated and wear protective gloves, goggles or face shield and an apron. Follow chemical manufacturer's use and safety recommendations.

Mineral spirits or mineral spirits based solvents are highly flammable. They must be stored and used in "No Smoking" areas away from sparks and open flames.

8.Do not weld on or near the diesel fuel tank until it has been thoroughly emptied and ventilated. Possible explosion could result if this precaution is not taken.

9.Failure to inspect parts thoroughly before installation, failure to install the proper parts, or failure to install parts properly can result in component or engine malfunction and/or damage and may also result in personal injury.

10.When working on an engine that is running, accidental contact with the hot exhaust manifold or catalytic converter can cause severe burns. Remain alert to the location of the rotating fan, pulleys and belts. Avoid making contact across the two terminals of a battery which can result in severe arcing.

11.Turbocharger air inlet shield - If operation of the engine is necessary without normal piping, use a turbocharger air inlet shield.

COOLING SYSTEM BASIC INFORMATION

A well maintained cooling system is a requirement for satisfactory engine performance and reliability. A knowledge of the application, duty cycle, and environmental conditions is essential when working on a cooling system to determine the cause of cooling system problems and to provide preventive maintenance. The cooling system must be maintained on a regular basis to prevent overheating, cavitation, corrosion, scale and gelation. Information contained in this Cooling Guide is intended to be used by qualified personnel familiar with diesel engine cooling systems.

Water is the most efficient heat transfer fluid. However, water alone can cause corrosion and contains minerals that produce scale deposits on internal cooling system surfaces. Chlorides, sulfates, magnesium, and calcium dissolved in the water can cause scale deposits, sludge deposits and/or corrosion. It may be necessary to have the water tested to determine the chemical content in your area. Distilled or deionized water is preferred to minimize the adverse effects of minerals in water. Never use water alone in the cooling system. A Detroit Diesel approved supplemental coolant additive is always required.

NOTICE:

Perkins® 500 Series engines have aluminum cylinder heads. These engines must use DDC/Perkins Power Cool® antifreeze to avoid engine damage. See Perkins 500 Series engine service manual.

Antifreeze is used for cold weather protection of the coolant. Antifreeze, also contains chemicals that provide protection against corrosion. The use of an antifreeze with a low silicate formulation that meets either the TMC RP 329 or ASTM D 4985 requirements is recommended.

For best overall performance with freeze protection, a 50% / 50% concentration of antifreeze and water is recommended. An antifreeze concentration over 65% glycol is not recommended because of poor heat transfer, reduced freeze protection, and possible inhibitor dropout.

A propylene glycol/water mixture also provides freeze protection. Propylene glycol is approved for use in Detroit Diesel Series 40, Series 50®, Series 55™ and Series 60® engines. For best overall performance, a 50% concentration of propylene glycol is recommended. It is **not** approved for use in other Detroit Diesel engines.

Propylene glycol must meet the performance of TMC RP330 and the physical/chemical requirements of ASTM D5216. The maintenance procedures for propylene glycol are the same as for ethylene glycol.

Methyl alcohol-based antifreeze must not be used in Detroit Diesel engines because of its effect on the non-metallic components of the cooling system and its low boiling point. Similarly, methoxy propanol-based antifreeze must not be used in Detroit Diesel engines because it is not compatible with fluoroelastomer seals found in the cooling system. Glycol-based coolants formulated for heating/ventilation/air conditioning should not be used in Detroit Diesel engines. These coolants generally contain high levels of phosphates, which can deposit on hot internal engine surfaces and reduce heat transfer. These deposits may also form on water pump seals and result in seal leaks.

Water Quality

Powertrac® 2-way Coolant Test Strips are used to measure nitrite concentrations and freeze point. Test strips are available in a bottle of 50, part number 23515917 or in a box of 100 individually sealed test strips, part number 23517268. A factory coolant analysis program is available through authorized Detroit Diesel service outlets under part number 23508774. Also, independent laboratories can perform water testing to determine the chemical concentration levels in your area.

Engine Coolant Temperature

The engine heat transferred to the coolant must be dissipated at a sufficient rate so engine coolant outlet temperature does not exceed established safe limits under all operating conditions. Tables 1 and 2 for Perkins engines indicate the maximum engine coolant outlet temperatures. In addition, the cooling system should maintain a minimum coolant outlet temperature of 160° F (71°C) or the minimum opening temperature of the thermostats during all ambient temperatures.

Extended periods of operation below the minimum coolant outlet temperature will cause carbon build up in the combustion chamber and exhaust passages.

Engine	Maximum Engine Coolant Outlet Temp. At sea level *
Military (combat only)	230°F (110°C)
Emergency Vehicle (road operation only)	230°F (110°C)
Series 149	200°F (93°C)
All other engines	210°F (99°C)

*See Service Manual for pressure cap setting.

Table 1

Perkins Engines

Maximum coolant outlet temperature

Pressure cap setting	sea level	4920 ft (1500 m)	8200 ft. (2500 m)	11480 ft (3500 m)
Non-pressure system	198°F (92°C)	189°F (87°C)	180°F (83°C)	174°F (79°C)
4 lb/in^2 (27.6 kPa)	210°F (99°C)	203°F (95°C)	198°F (92°C)	192°F (89°C)
7 lb/in^2 (48.3 kPa)	217°F (103°C)	212°F (100°C)	206°F (97°C)	201°F (94°C)

Note: For V8.640/TV8.640 engines, all the above temperatures must be reduced by 15°F (8°C)

Table 2

CAVITATION

Formation

Cavitation is caused by air bubbles collapsing on the outside of the cylinder liner walls during combustion (does not apply to dry liner engines). These air bubbles implode repeatedly against the side of the liner and can cause erosion of the liner that may progress into the combustion chamber.

Effects on components

Cavitation is aggravated by the liner vibration. The movement of the piston causes the cylinder liner to vibrate at a high frequency. When the liner vibrates, bubbles in the water passage next to the liner are formed. These bubbles then implode against the liner. This cavitation erosion can ultimately form pinholes in the liner.

Water pump

Cavitation of the water pump impeller and housing can be caused by trapped air in the cooling system or low system pressure.

Air leakage

Air can enter the cooling system through leaks or a faulty pressure cap. This reduces cooling system pressure and increases the potential for bubble formation in the coolant, which can cause an increase in metal surface pitting.

Low pressure

Low pressure can be caused by no pressure cap or a faulty pressure cap or air leakage into the cooling system.

Prevention

Since cavitation cannot be eliminated entirely, the use of supplemental coolant additives is necessary to provide a continued protective coating on the metal surface. This coating will control the cavitation and prevent damage to the engine.

Keep the cooling system clean with periodic flushing. The use of clean water with new antifreeze and supplemental coolant additives will reduce the effects of cavitation.

Always check the cooling system for leaks and radiator caps that do not seal properly. These conditions can cause air leakage into the cooling system that will reduce pressure and increase pitting on metal surfaces.

SUPPLEMENTAL COOLANT ADDITIVES (SCA)

SCA's provide protection for the cooling system components. The coolant must have the proper concentration of SCA's. Detroit Diesel maintenance products are recommended for use in all Detroit Diesel engines.

The proper application of SCA will provide:

- pH control to prevent corrosion
- Water-softening to deter formation of mineral deposits
- Cavitation protection to reduce the effects of cavitation

The proper dosages for initial cooling system fill and proper maintenance are required.

The concentration of SCA will gradually deplete during normal engine operation. Check the SCA concentration at the regular intervals. Additional SCA must be added to the coolant when it becomes depleted below the specified level. Maintenance dosage of SCA must only be added if nitrite concentration is less than 800 ppm. If nitrite concentration is greater than 800 ppm, do not add additional SCA.

A nitrite concentration of 2400 ppm or greater on Series 149 requires immediate draining and flushing of the cooling system. Refill the system with new coolant and the proper SCA dosage. Check the concentration level at the next maintenance interval.

CORROSION

Cast iron surfaces in a corrosive coolant will form iron oxide on the iron surface. This reddish-brown colored oxide formation on the corroded iron surface is more commonly referred to as rust. Other metals , likewise, form oxide layers, but corrode at different rates, depending on the condition of the coolant. The color of these various corrosion products can vary from red, green or black depending on the oxide that is formed.
A number of conditions in a cooling system will effect the degree and rate at which metal surfaces corrode and form these oxides: coolant pH, amount of dissolved oxygen and carbon dioxide in a coolant, metal surface deposits, metal stress, coolant temperature, and the supplemental corrosion inhibitors used. All the metal in a cooling system will corrode under different conditions and at varying rates.

Localized corrosion (Scale)

Cooling system deposits, such as hard water scale can form on cooling system surfaces. These deposits prevent heat from transferring to the coolant. This forms an area where accelerated corrosion can occur under and around the deposit, resulting in cooling system metal surface pitting. This type of corrosion is called localized corrosion.

The metal most prone to corrosion in a cooling system is aluminum, followed by cast iron, solder, steel, copper and brass. A major factor that has a direct impact on the rate of corrosion on any of the metals is a coolant's pH level.

Coolant pH level impact

The pH level runs from 0 to 14. A coolant becomes more acidic when the pH number is lower and becomes more alkaline when the number is higher. *Coolant pH should always be maintained between 7.5 to 11.*

Coolant pH Scale

0 7.5 11 14

acidic corrosion	optimum coolant pH Range	alkaline corrosion
iron steel copper brass		aluminum solder

If a coolant's pH drops below 7.5, it will become aggressive to ferrous metals (cast iron and steel), copper and brass. If it increases above 11, it will become aggressive to aluminium and solder in a cooling system. It is important to use a supplemental coolant additive containing a pH buffer that helps maintain the optimum pH range of a coolant.

Effects of temperature and metal stress on corrosion

Corrosion rates are directly related to coolant temperature. As coolant temperature increases, so does the rate of corrosion. Corrosion rates can double with every 25°F (13°C) to 50°F (28°C) rise in temperature, up to 160°F (71°C), where further increases in temperature have little effect.

Corrosion is also directly related to metal stress. As stress increases on metal joints or components in a cooling system, the potential for corrosion also increases. Soldered joint areas are some of the highest metal stress areas in a cooling system.

Dissolved solids

The amount of dissolved solids in a coolant can effect the corrosion reaction in a cooling system by increasing the coolant's electrical conductivity.

Chlorides and sulfates

High levels of dissolved chlorides and sulfates in coolant water will make the coolant very corrosive to all metal surfaces in the cooling system. Chlorides should never exceed 50 ppm, and sulfates should not be above 100 ppm.

Combustion leakage

During engine operation, engine combustion gases and particles can escape into the engine coolant system, at various rates, depending on engine seal conditions. These combustion products contain levels of carboxcylic acids, and oxides of sulfur and nitrogen. Sulfur and nitrogen combine with the engine's coolant to make the coolant acidic. These acidic coolant contaminants can drop the pH levels and increase the corrosion of steel and cast iron surfaces.

Solder corrosion

Solder corrosion ("solder bloom") is a typical corrosion deposit that grows around solder radiator tube joints. As lead corrodes, the lead corrosion byproducts combine with phosphates, which is commonly found in most antifreezes and in some corrosion inhibitors. These lead phosphate corrosion deposits continue to form and grow until they cut off coolant flows through radiator tubes. These deposits reduce the heat transfer capability by forming an insulation barrier.

Excessive lead corrosion at soldered tube joints can be caused by not cleaning off the flux used in a manufacturer's solder operation. Solder flux is an acid cleaner used to prepare the metal surface prior to soldering. If left on a lead soldered surface, it can accelerate lead corrosion.

SCALE

About 33% of the heat generated by a diesel engine must be removed by the cooling system to prevent engine damage. In order for the cooling system to remove this heat, it is critical that all cooling system surfaces remain clean.

Cooling system scale can restrict a cooling system's ability to transfer heat, resulting in engine operating problems. Scale 1/8 in. thick can reduce cooling system heat transfer by 40%.

Scale and deposits can cause failure of the cooling system if they insulate the coolant from the components which require cooling. The reduced heat transfer to the coolant causes overheating of the engine and may result in warping of components. It is not uncommon to have cracked heads or blocks, deterioration of hoses, loss of power, oil contamination and exhaust system failures when an overheated condition exists. Note, even with low coolant temperatures, this condition can occur.

Dissolved solids and water hardness

Cooling system water contains various levels of dissolved solids. Minerals like calcium carbonate (limestone), magnesium calcium carbonate (dolomite), calcium sulfate (gypsum), magnesium sulfate (epsom), and sodium chloride (salt), as well as various corrosion products and organic matter, are all part of potential contaminants found in engine cooling systems. As the amount of these contaminants increase, so does the probability that scale will occur.

The total dissolved solids in the water should be examined. Water hardness is the measure of the amount of dissolved salts of calcium and magnesium. As the measure of water hardness increases, the level of calcium and/or magnesium dissolved in water also increases.

If the total hardness is less than 50 ppm (3 grains per gallon), the water is soft and is likely to create minimal scale deposit problems. If the hardness is above 500 ppm (29 grain per gallon) it is considered extremely hard water. Total water hardness should not exceed 170 ppm (10 grains per gallon).

Scale formation

The formation of scale on hot metal cooling system surfaces is effected by many conditions that occur in a cooling system.

•Water hardness - The harder the water being used in an engine coolant, the greater the amount of scale formation.

•Temperature - As coolant temperature increases, hardness salts (calcium and magnesium) in solution become less soluble and increase scale on hot metal cooling system surfaces.

•Flow characteristics - Scale forms on the hot side of the cooling system and in areas of low flow. Water flowing over grooves, corners, sharp elbows and projections are areas of high scale formation.

•High phosphate - The use of high phosphate levels in anti freeze and supplement coolant additives (SCA's) will react with hard water (calcium and magnesium) to form scale.

•Corrosion due to scale deposits - Scale deposits in a cooling system lead to localized corrosion underneath the outlying boundaries of the scale deposit. Scale insulates and prevents heat from transferring from a covered metal surface. This results in localized corrosion and metal pitting.

Cooling system problems that result from scale formation

- **Scale problems on water pump seals** - Calcium and magnesium phosphate scale will form on water pump seal faces, preventing the water pump seal from sealing properly. This results in coolant leaks and premature seal wear.

- **Cracked heads and warped engine blocks** - Cooling system parts covered with scale will heat up beyond their designed temperature. When this happens, the increased heat levels can damage an engine component. Trapped heat can warp or crack engine blocks and cylinder heads.

- **Oil temperature running abnormally high** - Deposits of scale will form on the copper heat exchanger tubes of the engine oil cooler. These scale deposits block the heat transfer function of the oil cooler. This leads to high engine oil temperature and rapid oil breakdown.

- **Liners** - Excessive temperature on cylinder liners caused by scale will result in excessive cylinder kit wear. Piston ring scuffing and ring breakage are among the failures that could happen.

- **Failure of the cooling system fan to turn on** - Fan temperature sensors are placed on the hot side of a cooling system. If scale is formed on these surfaces, this barrier will prevent these sensors from sensing the actual temperature of the coolant.

- **Thermostat failures** - Scale has also been found to cause radiator thermostats to stick in a closed or open position. When this happens, cooling system temperature control is lost.

- **Scale deposits cause restriction of hot coolant return lines** - Scale deposits will form in the coolant return and vent lines and block the flow of coolant. Blockage of cooling system lines gives poor coolant flow and leads to high coolant temperature and further scale formation. Long, hot coolant return lines on buses and other installations are very susceptible to scale formation. Blockage will cause poor performance and lack of heater output. Vent line blockage will aerate the coolant.

- **Scale deposits on cooling system block heaters** - The hot surfaces of a cooling system block heater is an area where scale will form. When this happens, the block heater may continue to activate, overheat and burn out elements.

Scale removal from engine

To determine if you have a scale problem, first drain the engine coolant. Remove the radiator hose at the water pump inlet and look at the inside of the water pump. Scale will attach itself to the hot surfaces of the pump. Also, remove the thermostat and look inside the thermostat housing for indications of scale formation on the inside of the housing. Sometimes it is possible to look inside the radiator by removing the radiator cap and see scale build up on the radiator core.

If scale buildup is determined, a cooling system cleaning treatment will be required to remove the scale. Engine scale can be removed by using a cooling system cleaning treatment that is available from major chemical companies. Follow the directions and safety precautions provided with the treatment. Read the instructions before starting the process.

SILICATE GELATION

Sodium silicate is added to the antifreeze to protect the aluminum surfaces from corrosion and pitting. Silicate gelation is the tendency for silicate that is added to antifreeze to drop out of the solution and form a jelly like substance that will plug radiators, heaters, aftercoolers and other parts of the cooling system.

This drop out of silicate can be attributed to a combination of factors and cooling system interactions.

- Higher amounts of silicate and phosphate in coolant
- Hotter running engines
- Aftercoolers
- Additive packages

When antifreeze is overconcentrated, the excess silicate will drop out of the coolant and form the silicate gel on heat transfer surfaces. This results in reduced coolant flow and engine overheating. It is also possible for silicate to drop out at low coolant temperature and plug radiator tubes.

When the coolant has evaporated, it leaves a white, caked, powder like substance. The only way to remove small amounts of this gel is to agitate the components in a caustic solution. Care must be taken so that the O-rings, gaskets, seals and aluminum parts are not damaged.

The use of an antifreeze with a low silicate formulation that meets either the GM1899-M performance or ASTM D 4985 requirements is required.

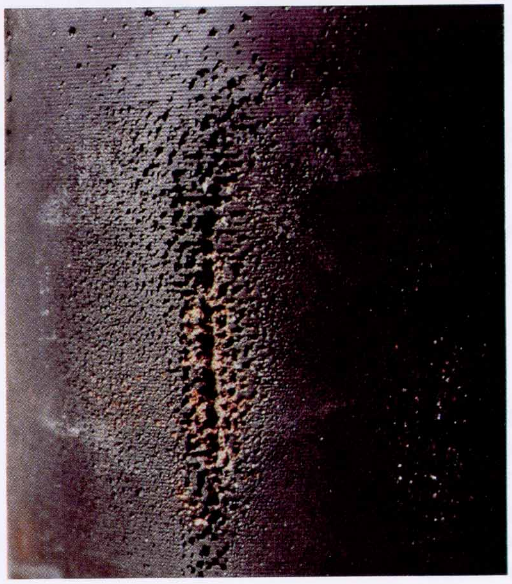
NOTICE:

Perkins 500 Series engines have aluminum cylinder heads. These engines must use DDC/Perkins Power Cool antifreeze.

INSPECTION AND ANALYSIS
COOLING SYSTEM

CONDITION:
Cylinder liner
cavitation

CAUSE:
Inadequate inhibitors
and trapped air in the
cooling system



RECOMMENDATION:
Do not reuse

CONDITION:
Cylinder liner
corrosion

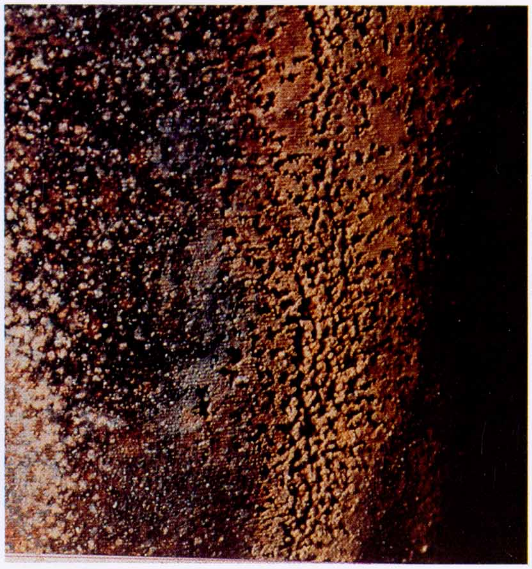
CAUSE:
Lack of coolant
additives

RECOMMENDATION:
Do not reuse

INSPECTION AND ANALYSIS
COOLING SYSTEM

CONDITION:
Metal component with localized corrosion

CAUSE:
Scale deposits on metal surface insulates the component and prevents heat from being transferred to the coolant



RECOMMENDATION:
Do not reuse

CONDITION:
Radiator tube blockage

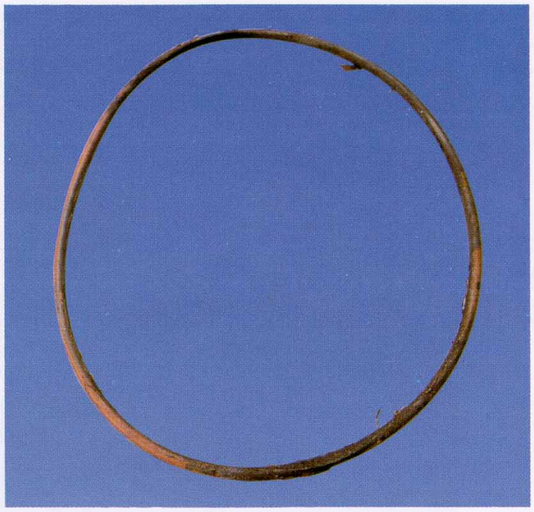
CAUSE:
Lead phosphate corrosion, lack of coolant additives. Also, high coolant temperatures

RECOMMENDATION:
Do not reuse

INSPECTION AND ANALYSIS
COOLING SYSTEM

CONDITION:
Brittle cylinder liner seal

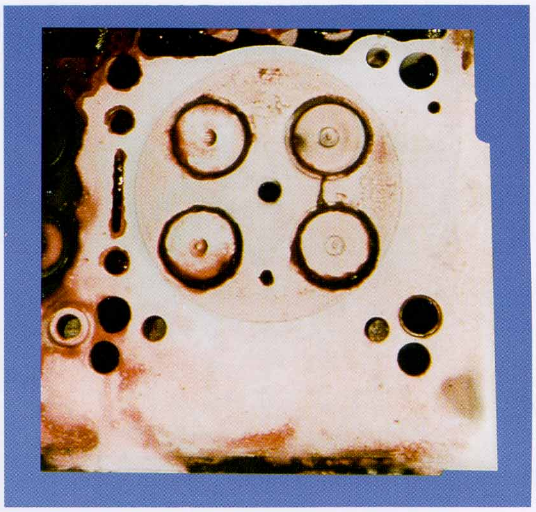
CAUSE:
Overheating of cooling system from scale deposit on temperature sensor giving false reading



RECOMMENDATION:
Do not reuse

CONDITION:
Cylinder head cracked

CAUSE:
Overheating of the cooling system caused by scale deposits from lack of additives

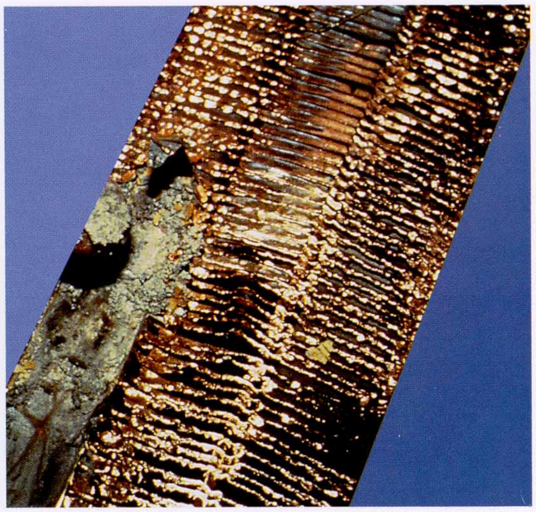


RECOMMENDATION:
Do not reuse

INSPECTION AND ANALYSIS
COOLING SYSTEM

CONDITION:
Oil cooler element with scale build up inside

CAUSE:
Hard water, high temperatures, and high phoshate levels of the coolant with poor water flows and lack of inhibitors



RECOMMENDATION:
Do not reuse

CONDITION:
Temperature sensor with scale buildup

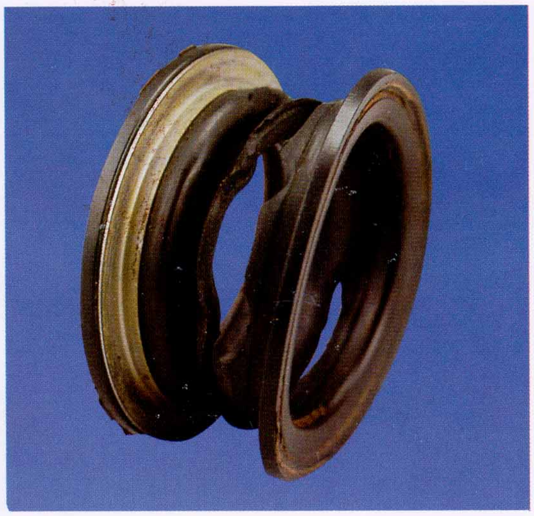
CAUSE:
High concentration of additives in coolant mixture

RECOMMENDATION:
Do not reuse

INSPECTION AND ANALYSIS
COOLING SYSTEM

CONDITION:
Chemical attack on water pump seal causing seal to deteriorate

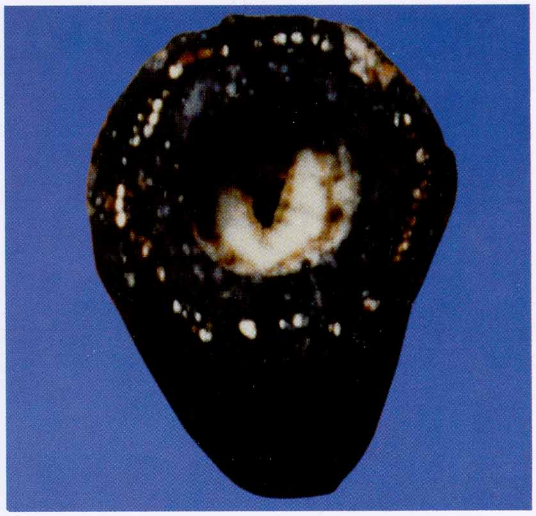
CAUSE:
Coolant additive package not properly maintained



RECOMMENDATION:
Do not reuse

CONDITION:
Coolant hose with silicate gel formation on inside

CAUSE:
Overconcentration of SCA and coolant mixture

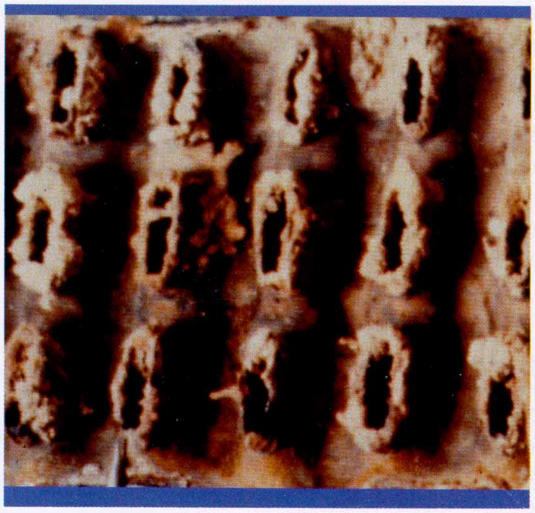


RECOMMENDATION:
Do not reuse

INSPECTION AND ANALYSIS
COOLING SYSTEM

CONDITION:
Radiator tube blockage

CAUSE:
Lower coolant temperature and high concentration of silicate causes silicate drop out



RECOMMENDATION:
Reuse, clean in accordance with the Service Manual procedure

COOLING SYSTEM MAINTENANCE

A schedule of periodic maintenance will provide for efficiency of the cooling system and extended engine life. Daily visual inspections should be made of the coolant level and the overall condition of the cooling system components. The items listed below should be checked for any signs of wear or damage, and if necessary corrective action must be taken. Anytime a coolant gauge, warning, shutdown, or low level device is malfunctioning, it must be repaired immediately to factory specifications.

Component	Condition to inspect
Coolant	Contaminated
Fan shroud	Loose, broken, or missing
Recirculating baffles	Missing, not sealing
Hoses/plumbing	Frayed, damaged, leaking, ballooning, or collapsing,
Radiator cap	Contaminated with oil, dirt and debris
Radiator	Fin and tube damage or blockage
Fill cap/neck	Dirty or damaged seats, gaskets/seal
Fan	Blades bent, damaged or missing
Belts/pulleys	Loose belts, frayed, worn, or missing

WATER

Water will produce a corrosive condition in the cooling system, and the mineral content may permit scale deposits to form on the internal cooling system surfaces. Chlorides, sulfates, magnesium and calcium make up the dissolved solids in water and may cause scale deposits, sludge or corrosion. Therefore, coolant inhibitors must be used to control corrosion and scale deposits.

ANTIFREEZE

INHIBITED ETHYLENE GLYCOL (IEG)

Ethylene glycol is used for freeze protection of the coolant. IEG, commonly referred to as antifreeze, also contains chemicals that provide a limited protection against corrosion. The use of an IEG product with a low silicate formulation that meets either the TMC RP 329 performance or ASTM D 4985 requirements is recommended.

Perkins 500 Series engines have aluminum cylinder heads. These engines must use DDC/Perkins Power Cool® antifreeze 23512138.

INHIBITED PROPYLENE GLYCOL (IPG)

An IPG/water mixture also provides freeze protection. Proylene glycol is approved for use in Detroit Diesel Series 40, Series 50, Series 55 and Series 60 engines. It is not approved for use in other Detroit Diesel engines.

Propylene glycol must meet the performance requirements of TMC RP-330 and the physical/chemical requirements of ASTM D5216. The maintenance procedure for propylene glycol are the same as for IEG. All references to IEG will also apply to IPG for the above approved series of engines

For best overall performance, a 50% concentration of IEG (1/2 IEG, 1/2 water) is recommended. An IEG concentration over 67% (2/3 IEG, 1/3 water) is not recommended because of poor heat transfer, reduced freeze protection, and possible silicate dropout. An IEG concentration below 33% (1/3 IEG, 2/3 water) offers little freeze or corrosion protection and is not recommended.

IEG and IPG coolants require the addition of SCA to provide cooling system corrosion and deposit protection. The SCA added should match the chemistry of the additive package included in the coolant. If this precaution is not observed, coolant monitoring can become difficult, making over inhibiting more likely. IEG formulations available in the market may contain from zero to the full amount of the required SCA. A basic IEG with no SCA must have additional SCA added at the time of initial fill. A "Fully Formulated" or "Precharged" IEG such as Detroit Diesel Power Cool® already contains the required SCA. Over concentration will result if SCA's are added to a fully formulated IEG coolant at the time of initial fill. This can result in solids dropout and the formation of deposits.

COOLANTS NOT RECOMMENDED

Methyl alcohol-based antifreeze should not be used in Detroit Diesel engines because of its effect on the non-metallic components of the cooling system and its low boiling point. Similarly, methoxy propanol-based antifreeze should not be used in because it is not compatible with fluoroelastomer seals found in the cooling system. Glycol-based coolants formulated for heating/ventilation/air conditioning (HVAC) should not be used in Detroit Diesel engines. These coolants generally contain high levels of phosphates, which can deposit on hot internal engine surfaces and reduce heat transfer.

SUPPLEMENTAL COOLANT ADDITIVES (SCA)

SCA's provide protection for the cooling system components. The coolant must have the proper concentration of SCA's. Detroit Diesel maintenance products are recommended for use in all Detroit Diesel engines.

The proper application of SCA will provide:

- pH control to prevent corrosion
- water-softening to deter formation of mineral deposits
- cavitation protection to reduce the effects of cavitation

The concentration of SCA will gradually deplete during normal engine operation. Check the SCA concentration at regular intervals. Additional SCA must be added to the coolant when it becomes depleted below a specified level. Maintenance dosage of SCA must only be added if nitrite concentration is less than 800 PPM.

NOTE: A nitrite concentration greater than 2400 PPM on Series 149 requires immediate draining and flushing of the cooling system. Refill the system with new coolant and the proper SCA dosage. Check the concentration level at the next maintenance interval.

NOTE: Excessive amounts of chemicals in the engine coolant can cause a gel-type or crystalline deposit that reduces heat transfer and coolant flow. The deposit, called "dropout," takes the color of the coolant when wet, but appears as a white powder when dry. It can pick up solid particles in the coolant and become gritty, causing excessive wear of water pump seals and other cooling system components. The wet gel can be removed by alkali type heavy duty cleaners, (Detroit Diesel maintenance product cleaner DD-2001). If the gel is allowed to dry, it is necessary to disassemble the engine and mechanically clean individual components.

SOLUBLE OILS

Soluble oil additives are not approved for use in Detroit Diesel engine cooling systems. A small amount of oil adversely effects heat transfer. A 1.25% concentration of soluble oil increases the fire deck temperature 6%. A 2.50% concentration increases the deck temperature 15%.

CHROMATE

Chromate additives are not approved for use in Detroit Diesel engine cooling systems. Chromate additives can form chromium hydroxide, commonly called "green slime or gel." This in turn, can result in engine damage due to poor heat transfer. Cooling systems operated with chromate-inhibited coolant must be chemically cleaned/conditioner (or equivalent sulfamic acid/sodium carbonate cleaner) and flushed. Some coolant filters elements with magnesium internal support plates have caused engine damage. The coolant dissolves the magnesium and deposits it on the hot zones of the engine where heat transfer is most critical. The use of elements with these plates is not approved.

DETROIT DIESEL COOLING SYSTEM MAINTENANCE PRODUCTS

Detroit Diesel maintenance products SCA are water-soluble chemical compounds. These products are available in coolant filter elements, liquid packages and a fully formulated IEG.

COOLANT FILTER ELEMENTS

Replaceable coolant filter elements (spin-on canisters) are available in various sizes suitable for cooling systems of varying capacity. Selection of the proper element size is vital when precharging the coolant system at initial fill and at maintenance intervals. A fully formulated IEG or IPG must not have SCA added at initial fill.

The need for maintenance elements is determined by the results of the SCA concentration test performed at each cooling system service interval.

TROUBLESHOOTING

LOSS OF COOLANT

The loss of engine coolant when no leaks appear can be the result of low or no pressure in the cooling system. The main cause for this condition is the pressure cap not sealing properly. This occurs when the design of the pressure cap does not match the system or when foreign material becomes lodged in the cap. Also, inspect the cap for damage as well as the neck of the radiator or top tank mating surface for damage.

It is also important that the radiator vent tube is not blocked or damaged. That would prevent proper venting of the cooling system. By preventing the cooling system from venting, the cooling system will not be allowed to build the proper amount of pressure until the engine coolant starts to boil. Proper venting of the system prevents cavitation of the water pump.

ENGINE OVERHEAT

SYMPTOMS

Obvious overheat conditions are determined from the coolant temperature gauge, warning, or shutdown devices. Steam vapor or coolant being expelled through the pressure relief overflow tube is another indication. Reduced engine performance or engine oil having a burnt odor are other indications.

COOLANT SIDE INVESTIGATION

Consider inaccurate gauge, warning or shutdown device, insufficient coolant flow and inadequate heat transfer capabilities during coolant investigation.

INACCURATE GAUGE, WARNING OR SHUTDOWN DEVICE

Check that the various temperature monitoring devices are in good working order. Sensor probes must be located (before the thermostat) in a high temperature, well mixed coolant flow path. The sensor must be free of scale and other contamination.

INSUFFICIENT COOLANT FLOW

1. Thermostat - Stuck; sluggish; worn; missing
2. Thermostat seal - Worn; missing; improper installation
3. Water pump - Impeller loose or damaged; drive belt loose or missing and/or worn pulley
4. Aerated coolant - Low level; excessive agitation of deaeration tank coolant; water pump seal failure; exhaust gas leakage (cracked cylinder head or block, damaged seals or gaskets, etc;) incorrect bleed line installation
5. Pressurization loss - Defective pressure cap/relief valve or seat; debris trapped between seats; internal or external leaks anywhere in the system
6. High restriction - Radiator plugged - solder bloom, silicate dropout, dirt, debris, collapsed hose(s) or foreign objects in the system
7. Coolant loss - Internal and external

INADEQUATE HEAT TRANSFER CAPABILITIES

1. Incorrect coolant mixture - Over/under concentration of antifreeze or inhibitors; incorrect antifreeze or inhibitors; corrosive water; incorrect antifreeze or inhibitor used; scale build-up
2. Contamination - Oil or other material depositing on heat transfer surfaces
3. Heat exchanger capability - Proper size for application.

AIR SIDE INVESTIGATION

Insufficient air flow, and inadequate heat transfer capabilities during air side investigation.

INSUFFICIENT AIR FLOW

1. High restriction - Plugged core; damaged or bent fins; shutters not opening correctly; addition of bug screens, winter fronts, and/or noise panels
2. Fan/Drives - Loose or worn belt and pulleys; improper drive engagement; fan installed backwards or damaged; adjustable fan blade setting; insufficient fan speed (drive ratio)
3. Shroud - Damaged or missing; not completely sealed
4. Fan positioning - Excessive fan tip to shroud clearance; incorrect fan placement in shroud; insufficient fan-to-core distance

INADEQUATE HEAT TRANSFER

1. Severe operating conditions - Inadequate coolant reserve capacity, Insufficient air flow
2. Core - Tube/fin separation; oil film, debris, contamination, etc.
3. Air recirculation - Radiator baffles damaged or missing; fan shroud/seal damaged or missing; wind conditions

OTHER FACTORS

1. Increased heat rejection; increased engine horsepower
2. Engine and/or cooling system modified
3. Increased engine loading or change in duty cycle
4. Running at more adverse condition than original system design permits; higher altitude and/or temperature

COLD RUNNING ENGINE (OVER-COOLING) OR ENGINE COOLANT TEMPERATURE BELOW NORMAL

Extended low coolant temperature operation can adversely affect engine performance, fuel economy and engine life. Overcooling most frequently occurs at extreme low ambient temperatures during long-term idling or low speed and load.

SYMPTOMS

Coolant temperature gauge reading are the usual indicators of a cold running engine. Other indications are low cab heat, white smoke or increased engine noise.

INVESTIGATION

1. Inaccurate gauge - calibration off; lack of markings to determine actual temperature; sensor probe in poor location or not fully submerged in a high coolant flow area
2. Closed thermostat core coolant flow - Top tank baffle not completely sealed; standpipe too short or missing; improper sizing of bleed line(s) or standpipe(s) so flow to the top tank exceeds fill line capacity; overfilled cooling system; addition of coolant recovery system; reverse core flow; thermostat(s) coolant leakage; thermostat(s) or thermostat housing(s) having bleed holes
3. Defective thermostat(s) - Stuck open; worn; misaligned; not installed; excessive leakage; out of calibration; incorrect start-to-open setting
4. Defective thermostat seal(s) - Worn; missing; located or installed incorrectly
5. Light load operation - Excessive low speed and load or idle operation; idle setting too low; over concentration of antifreeze and/or inhibitors; cab and fuel heaters, as well as, aftercoolers or intercoolers removing heat faster than engine can supply
6. Shutters/controls - Not fully closed; opening temperature set too low

POOR CAB HEATER PERFORMANCE

Consider the following to determine the reason for poor cab heater performance

1. Engine coolant temperature below normal
2. Coolant side causes
3. Air side causes
4. Thermostat leakage test
5. Radiator top tank baffle leakage test
6. Top tank imbalance test

COOLANT SIDE CAUSE

Low coolant flow and reduced heat transfer capabilities are coolant side causes for poor cab heater performance.

LOW FLOW

1. Supply and return lines not connected across high pressure drop point of the engine
2. Heater system too restrictive - core, plumbing size, bends, shutoff valves, length of circuitry
3. Parallel circuitry with multiple cores
4. If a water boost pump is used, it may be defective or not turned on
5. Air in heater circuit/coolant
6. Solder bloom, silicate dropout, dirt, debris
7. Shutoff valves not fully open
8. Fuel heater in circuit

REDUCED HEAT TRANSFER CAPABILITIES

1. Improper concentration or grade of antifreeze/inhibitors
2. Heater plumbing not insulated
3. Contamination of core tube surfaces - deposits
4. Fuel heater plumbed in cab heater circuit

AIR SIDE CAUSE

1. Improper air flow
2. Excess outside air through heater core
3. Core fins separated from tubes
4. Core surface contaminated - dirt, debris, oil film
5. Leaking air ducts
6. Malfunctioning air flow control valves

The interior of the cab should be completely sealed to eliminate direct air source and conserve available heat energy. Heat loss to the outside of the cab can be minimized by using thermal windows, reducing exposed metal surfaces, increasing insulation usage.

CAUTION:

Never remove the fill (pressure) cap when the coolant is hot. The system may be under pressure. Remove the cap slowly and only when the coolant is at ambient temperature. A sudden release of pressure from a heated cooling system can result in possible personal injury (scalding, eye injury) from discharge of the hot coolant.

THERMOSTAT LEAKAGE TEST

No coolant leakage should occur past the thermostat(s), seal or gasket when thermostat is closed. Over cooling may occur, resulting in poor engine performance, poor cab heater performance or both. The following test should be conducted on a cold running engine to determine if the thermostat is the cause:

CAUTION:

When working on an engine that is running, accidental contact with the hot exhaust manifold or catalytic converter can cause severe burns. Remain alert to the location of the rotating fan, pulleys and belts. Consider the hazards of the job and wear protective gear such as safety glasses, safety shoes, hard hats, hearing protection, etc. to provide adequate protection.

1. Prior to starting the engine. With the engine cold, remove radiator inlet hose(s) at the radiator and rotate so coolant can be collected in a container.
2. Fill system with cold water. Coolant will flow from the top hose into the container.
   If thermostat leakage occurs at this point, go to step four.
3. Start engine and accelerate to high idle and hold for approximately one minute. If leakage is more than a trickle, continue to step four. Otherwise go to step five.
4. Remove thermostat(s) and visually inspect thermostat, seals and the housing for obvious problems.
5. Replace any defective parts.

RADIATOR TOP TANK BAFFLE LEAKAGE TEST

The radiator top tank baffle must be sealed so no coolant can flow through the core during closed thermostat operation. The following test procedure will verify if there is a leakage problem:

1. Drain the cooling system (cold)
2. Plug the fill and bleed lines
3. Remove radiator inlet hose
4. Leave radiator drain plug open
5. Fill top tank to cold full level
6. Observe level in top tank and for coolant flow from drain and/or radiator inlet opening(s)
7. If coolant drains out of the top tank, it may indicate the baffle is not completely sealed and/or the standpipe(s) are too short and/or radiator inlet is not sealed or a vent hole was added
   If all of the coolant drains out of the top tank, it may indicate that the baffle is not completely sealed and/or standpipe(s) is missing, broken or incorrectly welded
8. Correct problem if a leak appears

TOP TANK IMBALANCE TEST

Top tank flow imbalance can cause coolant to flow through the standpipe(s) or radiator to the remote surge tank bleed line in either direction during closed thermostat operation, causing over cooling. Conduct the following test after the thermostat and top tank baffle leakage tests have confirmed no problems.

Install a sight glass with string (on both ends) in the radiator outlet hose near the radiator and before the fill and heater lines. This will permit a visual observation of the fill and bleed line flow direction and is useful in determining possible cause and solution for a top tank flow imbalance.

NOTE:
This test cannot be used if the engine water bypass flow is directed to the radiator bottom tank, such as for transmission coolers.

1. The test must be performed on a cold engine
2. The cooling system must be at the cold full level with no pressure cap
3. Start the engine and observe the string for coolant flow and direction as well as the fill and bleed lines. Continue making observations as the engine speed is slowly increased to high idle. If flow is observed in the sight glass, an imbalance exists
4. Correct problem of imbalance as outlined in following section

Reasons for top tank flow imbalance:

1. Bleed line sizes are too large
2. Fill line sizes too small and/or connecting fitting size too restrictive
3. Fill line connected to a pressure area. Visual observation of the fill line flow will show if the flow is incorrectly going to the surge tank
4. Main engine flow past fill line opening in top tank too restrictive
5. Standpipe(s) not above coolant level
6. Use of coolant recovery system

GLOSSARY

acid	A compound that yields hydrogen ions (H^+) when dissolved in water.
active metal	A metal ready to corrode or being corroded. Contrast with noble metal.
alloy	A substance having metallic properties and being composed of two or more chemical elements of which at least one is a metal.
alloy steel	Steel containing specified quantities of alloying elements added to effects changes in mechanical or physical properties.
alloy system	A family of alloys having in common a single, compositionally predominant metal.
alkaline	Having properties of an alkali, or having a pH greater than 7.
aluminum brass	A zinc alloy of copper containing 2% aluminum and 0.1% arsenic for inhibition of dezincification. Typical applications for this material are condenser, evaporator and heat exchanger tubing, condenser tubing plates, and ferrules. It is often specified when erosion resistance exceeding that of normal brasses is required.
annealing	A generic term denoting a treatment consisting of heating to and holding at a suitable temperature followed by cooling at a suitable rate used primarily to soften metallic material, but also to produce desired changes in other properties or in microstructure simultaneously. When the term is used by itself, full annealing is implied. When the treatment is applied only for the relief of stress, it is properly called stress–relieving or stress–relief annealing.
anode	The electrode of an electrolyte cell at which oxidation occurs. Electrode flow away from the anode in the external circuit. It is usually at the electrode that corrosion occurs and metal ions enter solution. Contrast with cathode.
anodizing	Forming a conversion coating on a metal surface by anodic oxidation; most frequently applied to aluminum.
applied stress	Stresses extrinsic to the material itself, such as those imposed by service conditions. Contrast with residual stress.
base metal	In welding, the metal to be welded, or after welding, that part of the metal that was not melted.
brass	An alloy consisting mainly of copper (over 50%) and zinc to which smaller amounts of other elements may be added.
brittle fracture	Separation of a solid accompanied by little or no macroscopic plastic.
bronze	A copper rich copper tin alloy with or without small proportions of other elements such as zinc and phosphorous.
caustic	A hydroxide of a light metal, such as sodium hydroxide or potassium hydroxide.
cavitation	The formation and instantaneous collapse of innumerable tiny voids or cavities within a liquid subjected to rapid and intense pressure changes.
cavitation damage	The degradation of a solid body resulting from its exposure to cavitation. This may include loss of material, surface deformation, or changes in properties or appearance.
cementite	A compound of iron and carbon, know chemically as iron carbide and having the approximate chemical formula Fe_3C.

chevron pattern	A fractographic pattern of radial marks that resemble nested letters V. Chevron patterns are typically found on brittle fracture surfaces in parts whose widths are considerably greater than their thickness. The points of the chevrons can be traced back to the fracture origin.
closed recirculating	A cooling system in water is recirculated in a closed loop. Such systems experience little, if any exposure to the atmosphere.
cold flow	Deformation of an elastic material resulting from stresses applied at ambient temperatures.
cold work	Permanent deformation of a metal produced by an external force.
corrosion	The chemical or electrochemical reaction between a material, usually a metal, and its environment that produces a deterioration of the material and its properties.
corrosion fatigue	The process in which a metal fractures prematurely under conditions of simultaneous corrosion and repeated cyclic loading at lower stress levels or fewer cycles than would be required in the absence of the corrosive environment.
corrosion product	Substance formed as a result of corrosion.
corrosivity	The tendency of an environment to cause corrosion in a given corrosion system.
crevice corrosion	A type of concentration cell corrosion; corrosion caused by the concentration or depletion of dissolved salts, metals ions, oxygen or other gases, and such, in crevices or pockets remote from the principal fluid stream, with a resultant buildup of differential cells that ultimately cause deep pitting.
cupronickel	A copper based alloy containing 5 to 30% nickel.
cyclic stress	A stress whose magnitude fluctuates.
dealloying	The selective corrosion of one or more components of a solid solution alloy. Also called parting or selective leading.
defect	An imperfection in a material that contributes significantly to failure or limited serviceability. Contrast with flaw.
denickelification	Corrosion in which nickel is selectively leached from nickel containing alloys.
ductile fracture	Fracture characterized by tearing of metal accompanied by appreciable gross plastic deformation and expenditure of considerable energy.
ductility	The ability of a material to deform plastically without fracturing.
electrolyte	An ionic conductor or a liquid, most often a solution, that will conduct an electric current.
erosion	Destruction of metals or other materials by abrasive action of moving fluids, usually accelerated by the presence of solid particles or matter in suspension.

exfoliation	A type of corrosion that progresses approximately parallel to outer surface of the metal, causing layers of the metal or its oxide to be elevated by the formation of corrosion products.
failure	A general term used to imply that a part in service has become completely inoperable, or is still operable but is incapable of satisfactorily performing its intended function, or has deteriorated seriously to the point that it has become unreliable or unsafe for continued use.
fatigue	The phenomenon leading to fracture under repeated or fluctuating mechanical stresses having a maximum value less than the tensile strength of the material.
fatigue limit	The maximum stress that presumably leads to fatigue fracture in a specific number of stress cycles.
ferrite	Designation commonly assigned to alpha iron-containing elements in solid solution.
ferrous hydroxide	A white corrosion product of iron, $Fe(OH)_2$. Ferric ion incorporated in the substance will alter the color to green, brown, or black.
flaw	An imperfection in a material that does not affect its usefulness or serviceability.
flow-induced vibration	Tube vibration resulting from the mechanical effects of fluids impinging on tube surfaces. Such vibrations may induce wear or cracking, especially if the tubes vibrate at their natural frequency.
flux	A welding material used to prevent the formation of or to dissolve and facilitate the removal of oxides and other undesirable substances.
fretting	A type or wear that occurs between tight fitting surfaces subjected to cyclic, relative motion of extremely small amplitude.
galvanic cell	A cell in which chemical change is the source of electrical energy. It usually consists of two dissimilar conductors in contact with each other and with an electrolyte or two similar conductors in contact with each other and with dissimilar electrolytes.
galvanic corrosion	Corrosion associated with the current of a galvanic cell.
galvanic potential	The magnitude of the driving force in an electrochemical reaction resulting from the coupling of dissimilar material exposed to a common, corrosive environment.
galvanic series	A series of metals and alloys arranged according to their relative electrode potentials in a specified environment.
gas porosity	Fine holes or pores within a metal that are caused by entrapped gas or by evolution of dissolved gas during solidification.
grain	An individual crystal in a polycrystalline metal or alloy.

grain boundary	A narrow zone in a metal corresponding to the transition from one crystallographic orientation to another, thus separating one grain from another.
graphitic corrosion	Corrosion of gray or nodular cast iron in which the iron matrix is selectively leached away, leaving a porous mass of graphite behind; it occurs in relatively mild aqueous solutions and on buried pipe fittings.
holidays	Discontinuities in a coating (such as porosity, cracks, gaps, and similar flaws) that allow areas of base metal to be exposed to any corrosive environment that contacts the coated surface.
hydrated ferric oxide (ferric hydroxide)	A flaky, red to brown corrosion product of iron or steel that forms upon exposure to subterranean, atmospheric, or aqueous environments, $Fe_2O_3.3H_2O$.
hydrolysis	A chemical process of decomposition involving splitting of a bond and addition of the elements of water.
hydrous ferrous ferrite	The hydrated form of ferrosoferric oxide, Fe_3O_4, a black, magnetic corrosion product,$Fe_2O_4.nH_2O$. It is oxidized to hematite, $Fe_2O_{3,}$ when heated in air.
hydrous ferrous oxide	The hydrated form of ferrous oxide, FeO, a jet black corrosion product, $FeO.nH_2O$. It is readily oxidized by air.
intergranular corrosion	Corrosion occurring preferentially at grain boundaries, usually with slight or negligible attack on the adjacent grains.
laminar flow	Streamlined flow in a fluid.
lap	A surface imperfection, with the appearance of a seam, caused by hot metal, fins, or sharp corners being folded over then being rolled or forged into the surface but without being welded.
local action	Corrosion caused by “local cells” on a metal surface.
local cells	A cell, the emf of which is due to differences of potential between areas on a metal surface in an electrolyte.
magnetite	A magnetic form of iron oxide, Fe_3O_4, Magnetite is dark gray to black and forms a protective film on iron surfaces.
matrix	The principal phase on which another constituent is embedded.
microstructure	The structure of a metal as revealed by microscopic examination of the etched surface of a polished specimen.
mild steel	Carbon steel having a maximum carbon content of approximately 0.25%.
noble metal	A metal with marked resistance to chemical reaction, particularly to oxidation and to solution by inorganic acids.

passivation	The changing of a chemically active surface of metal to a much less reactive state.
passivity	A condition in which a metal because of an impervious coving of oxide or other compound, has a potential much more positive than a metal in its active state.
penetration	In welding, the distance from the original surface of the base metal to the point which fusion ceases.
pH	The negative logarithm of the hydrogen ion activity; it denotes the degree of acidity or basicity of a solution. At 77°F (25°C), 7.0 is the neutral value. Decreasing values below 7.0 indicate increasing acidity; increasing values above 7.0 indicate increasing basicity.
pipe	The central cavity formed by contraction metal, especially ingots, during solidification.
pit	A distinct cavity in a metal surface resulting from highly localized corrosion.
pitting	Forming small sharp cavities in a metal surface by corrosion.
plain carbon steel (ordinary steel)	Steel containing carbon up to about 2% and only residual quantities of other elements except those added for deoxidation.
plate-and-frame heat exchanger	An exchanger that consists of a stack of thin plates supported in a frame. The plates are typically corrugated. The two fluids flow along opposite sides of each plate.
residual stress	Stresses that remain within a body as a result of plastic deformation.
root crack	A crack in either the weld or heat-affected zone at the root of a weld.
root of joint	The portion of a weld joint where the members are closest to each other before welding. In cross section, this may be a point, a line, or an area.
root of weld	The points at which the weld bead intersects the base-metal surfaces either nearest to or coincident with the root of joint.
rust	A corrosion product consisting of hydrated oxides of iron.
seam	On a metal surface, an unwelded fold or lap that appears as a crack, usually resulting from a discontinuity.
seam welding	Making a longitudinal weld in sheet metal or tubing.
selective leaching	Corrosion in which one element is preferentially removed from an alloy, leaving a residue (often porous) of the elements that are more resistant to the particular environment.
shell-and-tube heat exchangers	The most widely used form of heat exchanger in which one fluid passes through a number of tubes housed in a shell. The second fluid passes through the shell.
siphonic gas exsolution	The formation of gas bubbles in a fluid caused by decreasing fluid pressure associated with flow.

spalling	The cracking and flaking of particles out of a surface.
stainless steel	Any of several steels containing 12 to 30% chromium as the principal alloying element; the steels usually exhibit passivity in aqueous environments.
static stress	A stress whose magnitude remains at a constant value. Contrast with cyclic stress.
stress	Force per unit area, often thought of as force acting through a small area within a plane. it can be divided into components, normal and parallel to the plane, called normal stress and shear stress, respectively. True stress denotes the stress where force and area are measured at the same time. Conventional stress, as applied to tension and compression tests, is force divided by original area.
stress–corrosion cracking	Failure by cracking under the combined action of a specific corrosive and stress, either external (applied) stress or internal (residual) stress. Cracking may be either intergranular or transgranular, depending on the metal and the corrosive medium.
stress frequency	The number of times a stress cycle is repeated in a unit of time.
stress raisers	Changes in contour or discontinuities in structure that cause local increases in stress.
tensile strength	In tensile testing, the ratio of maximum load to original cross–sectional area. Also called ultimate strength.
transgranular	Through or across crystal or grains. Also called intracrystalline or transcrystalline.
tubercle	A knoblike structure of corrosion products that forms over corrosion sites on iron–based metals.
tuberculation	The formation of localized corrosion products in the form of knoblike mounds called tubercles.
twin	Two portions of a crystal having a definite crystallographic relationship. Twins can be thermally or mechanically produced.
underbead crack	A subsurface crack in the base metal near a weld.
weld	A union made by welding.
weld bead	A deposit of filler metal from a single welding pass.
welding current	The current flowing through a welding circuit during the making of a weld.
weldment	An assembly whose component parts are joined by welding.
weld metal	That portion of a weld that has been melted during welding.
yield strength	The stress at which a material exhibits a specified deviation from proportionality of stress and strain. Compare with tensile strength.

NOTES

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