WEAR CHECK® AFRICA
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TECHNICAL BULLETIN
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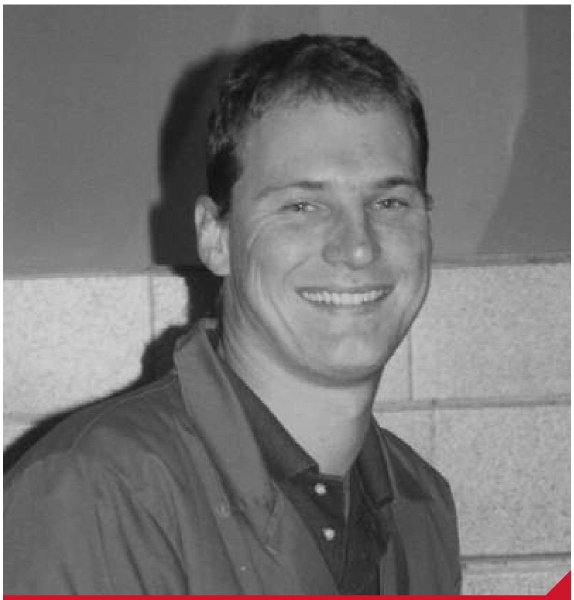
WEARCHECK
CONDITION MONITORING THROUGH OIL ANALYSIS

KEEP YOUR COOL

by Neil Robinson, B. Sc. Hons.



> "DEPENDING ON WHOM YOU TALK TO, BETWEEN 40 AND 60 PERCENT OF TODAY'S PREMATURE HEAVY-DUTY DIESEL ENGINE OVERHAULS ARE RELATED TO COOLING SYSTEM PERFORMANCE."
>
> Neil Robinson

During operation, all internal combustion engines produce heat as a by-product of combustion. The temperature of burning fuel can reach 2000°C. However, only about 33% of this is transferred into power through the crankshaft. Approximately 30% is expelled through the exhaust whilst another 7% or so is lost through radiation. The remaining 30% must be dissipated through a cooling system *(Figure 1)*. In addition to removing heat from burnt fuel, the cooling system also removes heat from other sources such as turbochargers, torque converters and hydraulic or transmission oil coolers.

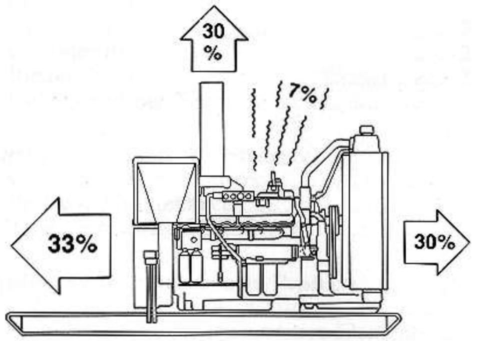


Figure 1. Paths to heat loss

Higher engine temperatures can achieve greater efficiencies. Therefore, as we place more stress on the engine, the coolant itself is quickly becoming the weak link in this system. Overheating, overcooling, pitting, cavitation erosion, cracked heads, piston seizures, reduced critical clearances, lower oil viscosity, increased wear and plugged radiators are classic cooling system failures. The function of a coolant and the cooling system is to remove the right amount of heat and keep the engine running at the correct temperature.

Early cooling systems simply used water because of its good heat transfer properties and availability. However, some properties of water such as its high freezing and low boiling points, limit its usefulness as a coolant. The natural corrosive action of water on metals, especially at high temperature, is also undesirable.

A modern heavy-duty diesel engine coolant is a carefully designed and complex mix of chemicals, each fulfilling a particular role in the final product. The most common of these are shown below:

CHEMICAL	FUNCTION	
Borates, phosphates	Buffers -	these maintain the proper pH of the coolant as well as providing some corrosion protection.
Silicones, polyglycols	Antifoam -	prevent coolants from forming stable foams that can cause pump cavitation and overheating.
Nitrates, silicates, MBT, tolytriazole and some organic acids	General corrosion -	provide corrosion protection to a variety of different metals.
Nitrites, molybdates, organic acids	Cavitation protection -	provide cast iron cavitation corrosion protection.
Polyacrylates and various other water soluble polymers	Scale inhibitors -	prevent mineral and corrosion product deposits on hot surfaces.
Detergents, dispersants	Anti fouling -	prevent/limit oil and dirt build-up on metal surfaces.

COOLANTS

SCAs, OAT, carboxylates, ELCs, extenders . . . what does it all mean? Essentially all coolants consist of the same combination of a bulk liquid and additive package.

THE LIQUID

The liquid has two main functions: that of a solvent and as the main heat transfer medium. The liquids most commonly used are ethylene glycol/water mix, propylene glycol/water mix and water on its own. The glycols are generally used at a 30- 50% mix with water, and impart freeze and boil protection to the coolant and subdue water pump cavitation.

1. Ethylene glycol has very good heat transfer properties, but is toxic. At 50% it offers boil protection to 108°C and freeze protection down to -37°C.

2. Propylene glycol has less effective heat transfer properties, but is considered non-toxic (however, once additives have been added, it should be treated as toxic). A 50% propylene glycol mix offers similar freeze and boil protection to ethylene glycol.

3. Water has the best heat transfer properties but less desirable freeze and boil protection. Whenever water is used in a cooling system, the best quality water available should always be used. Never use salt water, and hard water should be treated. Ideally deionised or distilled water is recommended.

THE ADDITIVES

To simplify matters we will use the generic term of antifreeze to mean a glycol water mixture or, in warmer climates where freeze protection is not required, pure water may be used on its own.

1. Antifreeze + conventional corrosion inhibitor. These products are available as fully formulated, phosphate free, low silicate, extended service coolants (ELC). They are commercially available as either a concentrate or as a premix. The premixed antifreeze is ready for use while the concentrate must be mixed with water prior to use.

2. Antifreeze + Organic Acid Technology (OAT) inhibitor. OAT or carboxylate coolants require less maintenance over the useful life of the engine than conventional coolants. The cooling system should ideally be equipped with a normal filter. These are available as both concentrate and premix, as in conventional coolants. However, they should not be mixed. If they are, the long life advantages of the OAT will be lost. In this event, the coolant should be maintained as a fully formulated extended service coolant.

3. Supplemental Coolant Additives (SCAs) + OAT extender. The concentration of some of the coolant additives will be consumed during normal engine operation. This depletion is accelerated under abnormal operation or cooling system deficiencies. These additives will therefore need to be replenished at the appropriate intervals. SCAs and extenders, either in the form of concentrate or screw-on filters, are designed to replenish the additive concentration of the coolant, allowing it to offer continued protection to the engine. For these products to be effective, it is important that the additive packages are monitored to prevent over or under dosing. Both cases can produce a range of problems, as identified below.

COOLING SYSTEM PROBLEMS

Most cooling system problems and failures occur due to incorrect information and maintenance practices. The most common problems and effects seen in today's cooling systems are described below.

ACID / ALKALINITY BALANCE

A coolant's acidity or alkalinity is measured by its pH. The pH level ranges from 1 to 14 and indicates the degree of acidity or alkalinity of the coolant and is related to its corrosiveness. Ideally the cooling system's pH should be between 8.5 and 10.5. When the pH is too high, the coolant becomes alkaline and will attack non-ferrous materials such as copper and aluminium. When the pH is too low, it becomes acidic and will begin to attack both aluminium and ferrous materials producing 'blooms'. As the metal surfaces react with the acid, deposits build up on exposed edges within the cooling system. These deposits can also be transported and deposited throughout the cooling system, restricting flow and causing overheating. Coolants contain buffering agents to maintain an optimal pH level and to neutralise acids produced by oxidation and blow-by gases *(Figure 2).*

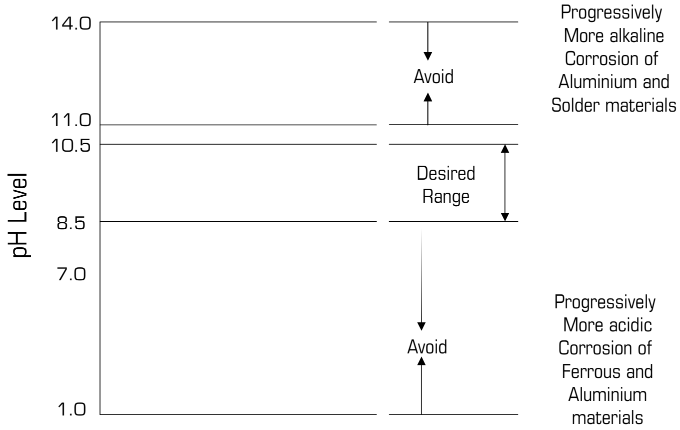


Figure 2. pH Scale for coolant mixture

CAVITATION EROSION (LINER PITTING)

Many modern diesel engines contain cast iron replaceable cylinder liners that due to the nature of engine design and high compression ratios can be subjected to accelerated corrosion by a process known as cavitation. During combustion the pistons strike the liners as they travel up and down due to the side thrust imparted by the connecting rods as the power is translated from the linear motion of the piston to the rotary motion of the crankshaft. The clearance between the piston and the liner, and the liner and the block, allows this 'piston slap' to be translated into a high frequency vibration, much like that of a bell when it is struck.

As the liner moves away from the coolant in the block it produces 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 forcing the newly formed bubbles to collapse against the wall of the liner at pressures as high as 4000 bar. The collapse of these bubbles blasts small holes in the oxide layer of the liner exposing the bare metal, which is then rapidly corroded.This process of cavitation corrosion will repeat many times digging tiny tunnels through the liner.

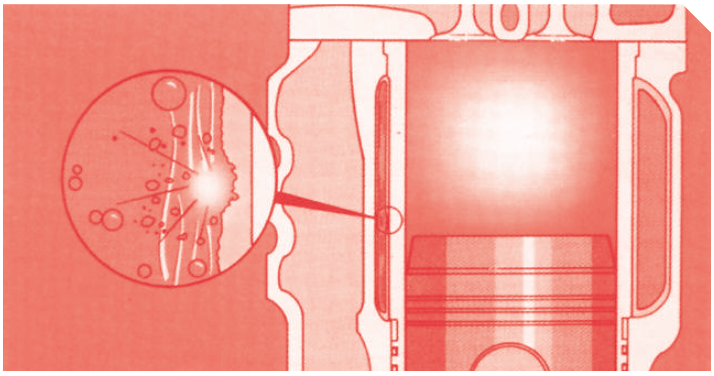


Figure 3. The cavitation erosion process

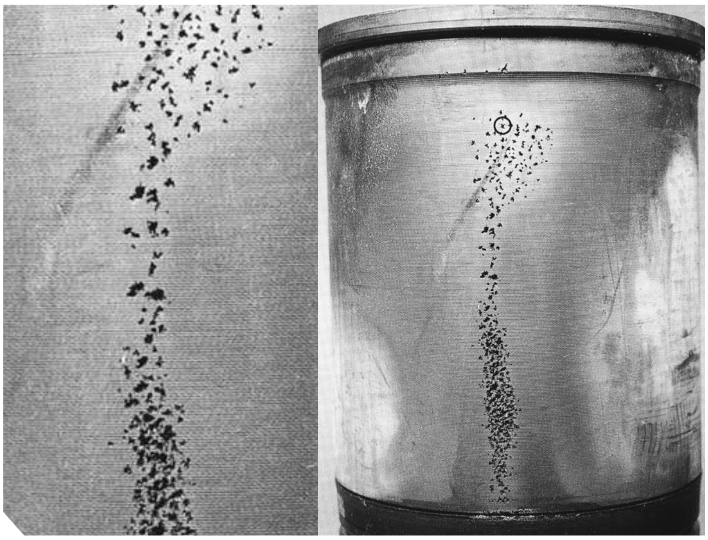


Figure 4. Cavitation erosion on a cylinder liner

Eventually the liner wall is penetrated allowing oil and/or coolant to flow from one side to the other. This effect can be magnified when an engine is run cold or the cooling system pressure is low.

Nitrite and nitrite/molybdate containing coolants prevent this in two ways. Firstly, the nitrite itself reacts with the oxygen at the surface of the liner and, in doing so, prevents oxidative corrosion of the liner surface. Secondly, it forms a tough thin layer on the liner surface which is continually removed and formed, protecting the liner.

In the organic acid type coolants, carboxylic acids react with liner surfaces to form an insoluble iron carboxylate layer that prevents corrosion-causing oxygen getting to the surface of the metal. The sebacates in the coolant form a hard waxy film, which is modified further by other additives making it more resilient (energy absorptive and flexible) and resistant to cavitation erosion. With sufficient energy however, these films can be blasted from the surface of the iron, and the process will start again.

It has been shown that optimal liner pitting protection is derived from coolants containing a mixture of organic acids and nitrites. Here there is a symbiotic relationship and, if the cavitation energy increases above the levels that the carboxylates can protect, i.e. it is blasted from the surface, the nitrite can still prevent corrosion by reacting with the oxygen at the newly exposed iron surface.

When plain water is used as a coolant, liners can be penetrated in as little as 500 hours.

SCALE AND DEPOSIT FORMATION

Scale and other deposits similar to those formed on the elements of water boilers and hot water pipes, can also form on the inside of the cooling system. The general characteristics of the water - including pH level, calcium and magnesium salts, total hardness, dissolved solids and temperature - determines scale and deposit formation. Common scale deposits include salts such as calcium carbonate and sulphate. Scale and deposit formations are detrimental to the cooling system because they act as insulators and can block a cooling system's ability to transfer heat, resulting in overheating. Only 2mm of scale can reduce heat transfer efficiency by as much as 40%. Scale tends to form in specific areas on the hot side of the engine causing localised hotspots which, in turn, can cause distortion and damage to the engine. Properly maintained coolants contain additives, which help prevent the formation of scale.

AERATION

Air leakage into the cooling system often results in coolant foaming. Foaming promotes pitting, particularly around water pump impellors. Pitting and corrosion increase significantly when exhaust gases enter the cooling system, introducing bubbles and foam. This is especially significant when coolant operating pressure is low. Properly maintained coolants contain de-foaming additives that reduce foam stability.

RUST

Rust is caused by oxidation within the cooling system. Heat and moist air accelerate this process. Rusting leaves residual scale deposits that reduce the efficiency of the cooling system. Additionally the rust may flake off, clogging the cooling system, and accelerate corrosive wear of pumps and hoses.

ELECTRICAL CORROSION

There are essentially two forms of electrical corrosion: galvanic and electrolytic. Both are dependent on the ability of the coolant to carry electrical charge which, in turn, is dependent on the cleanliness of the coolant and the dissolved solids in it. Those coolants containing glycols have a lower tendency to carry charge than those that are only inhibited water.

GALVANIC CORROSION

This is an everyday phenomenon where two or more dissimilar metals are in contact in the presence of an electrolyte and form an electrolytic cell or battery. In this case the electrolyte will be the coolant. An electromotive force, or electrical 'pressure' exists between the metals such as the iron engine block and the aluminium radiator. In order to re-establish equilibrium the lower voltage metal becomes the anode and discharges a current into the coolant to complete the circuit and in doing so the metal, usually the aluminium radiator, is corroded *(Figure 5)*.

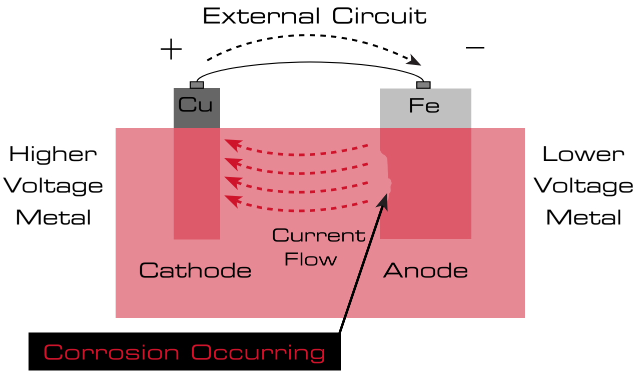


Figure 5. The galvanic corrosion process

ELECTROLYTIC CORROSION (ELECTROLYSIS)

This is a fast acting menace that attacks not only radiators and heaters, but can destroy an entire engine in as little as 30 000 km. In this case, electricity provides the necessary energy to cause otherwise non spontaneous reactions to occur. Electroplating is an example of electrolysis. In the automotive world this is usually in the form of a defective or missing ground on an electrical device *(Figure 6)*.

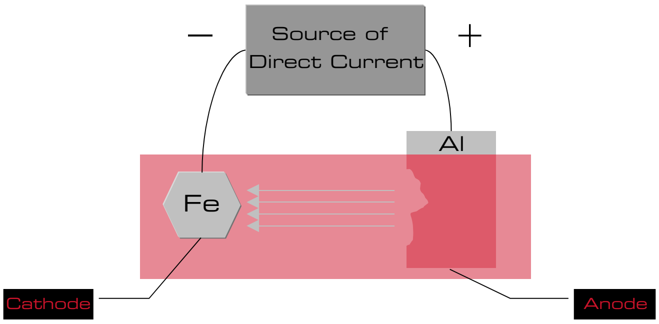


Figure 6. The electrolytic process

This causes electricity to seek the path of least resistance whenever the component is energised. As the current draw of the poorly grounded device increases, so does the destructiveness of the electrolysis. A poorly grounded engine or starter motor can put enough current through the cooling system to destroy a radiator in a matter of days, depending on how often the vehicle is started. A partially grounded cooling fan on the other hand may only leak a small percentage of its current through the cooling system and the effect may take months to reveal itself.

Evidence of these types of corrosion includes unexplained or recurring pinhole leaks in a radiator or heater. Pinholes may form anywhere along the tubes or tank walls but damage is often concentrated at tube to header joints or in the tube walls near the centre of the core where the electric cooling fan mounts come into contact with the core. This form of corrosion will also rapidly reduce the protective additives in the coolant leading to cavitation corrosion, and can cause the formation of ammonia leading to increased alkalinity of the coolant and subsequent copper and aluminium corrosion.

ADDITIVE LOSS

Additive loss is due to three basic processes: depletion, dilution and dropout.

1. DEPLETION

This is caused mainly by the following chemical processes:

- Oxidation and reduction on metal surfaces
- Adsorption
- Neutralisation
- Thermal degradation
- Hydrolysis
- Precipitation

The first three of these mechanisms involve the coolant doing its intended job of forming protective films on metal surfaces and neutralising acids that form within or enter the coolant. These chemical processes of additive removal from the coolant are in turn controlled by several factors:

- Engine dynamics
- Make up water quality
- Cavitation
- Aeration
- Galvanic coupling
- Engine displacement vs. cooling system capacity
- Contamination

2. DILUTION

This takes place when coolant is lost and the system is topped up with water. Coolant loss can occur in several ways:

- Leaking cooling system components
- Overfilling
- Overheating
- Loss during engine repair

It is generally overfilling that causes gross coolant loss. Often a mechanic or driver will top-up to overflow. When the vehicle is put into service the coolant heats up, expands and forces several litres of coolant out of the system. If this occurs on a daily basis rapid additive dilution can occur.

3. DROPOUT

When coolant is over concentrated with SCAs the excess additive, usually the excess silicate, will drop out of the coolant and form jelly-like substances that will plug radiators, aftercoolers etc., and can cause premature water pump failures. This drop out of silicate can be attributed to a combination of factors and cooling system interactions including:

- Higher amounts of silicate and phosphates in the coolant
- Hotter running engines
- Additive packages

DO YOU NEED FILTERS?

Unlike oil or fuel filters, coolant filters are basically dispensers of chemistry. So are they even necessary? Because coolant filters containing conventional SCAs should not be used on engines filled with ELCs, some manufacturers do not install a filter at all on engines filled with this kind of coolant. However, in addition, SCA dispensing filters can serve an important psychological purpose at maintenance intervals. When that filter is sitting there in that row of filters, it is a visual reminder to check the cooling system. What must not be forgotten is coolant filters do perform a filtration function. As a bypass filter, it only takes a small percentage of the total fluid that is circulating through the system and puts it through the filter. Rust, scale and other debris will be removed to keep them from circulating in the engine, wearing out the pump bearings and causing erosion, etc. Filters can also warn of problems in the cooling system. It should be recognised that the coolant and the additives are there to keep rust from occurring. If there's rust appearing inside the filter, the chances are that something is happening in the engine.

WHAT TO DO . . .
AND WHAT NOT TO DO

- Avoid phosphate-based coolants; dropouts, overheating and water pump seal failures can result.
- Do not use passenger car type coolants; they offer no liner pitting protection and often contain high levels of silicates and phosphates.
- Do not use methyl alcohol or methoxy propanol based antifreezes; these can cause damage to non-metallic components and fluoroelastomer seals found in cooling systems and have low boiling points.
- Do not use soluble oils; a small amount of oil effects heat transfer and can result in overheating.
- Do not use anti-leak additives if a cooling system filter is used; these may become plugged.
- Do not add undiluted coolant concentrate as make-up coolant.
- Do not add plain water as make-up.
- Do drain and flush the cooling system every two years.
- Do use the best quality water available.
- Do periodically check bulk premixed coolant storage tanks for chemical separation and contamination.
- Do use coolant mixed at the correct proportions for make-up.
- Do periodically test coolant for additive levels and contamination.
- Above all, follow engine or vehicle manufacturer guidelines for coolants and cooling system maintenance.

It is apparent that the maximum return is achieved by using the best possible coolant and maintaining it as close to its original performance level as possible for as long as possible and changing it when it degrades sufficiently to warrant doing so. Coolant analysis is one of the tools we can use to accomplish this. This can become even more important where increased drain intervals are being implemented. Mechanical maintenance and operational problems can lead to degradation of even the best coolant and the first sign of a problem can be a catastrophic mechanical failure caused by a cooling system failure. If an engine was running perfectly, it was operated and maintained correctly and had no design flaws or long term component failures, then the quality of the coolant would determine when it should be changed. However, in the real world this is not the case. Eventual failures that could have been avoided by monitoring the coolant condition can be caused by a drop in pH due to glycol oxidation or exhaust gas entry, or an increase in pH due to ammonia formation, or loss of nitrite due to electrolysis or oxidation. By extending the length of time the coolant is in the engine, the probability of these failures occurring increases and with increased coolant service life there is a need, more than ever, to evaluate the coolant at regular intervals.

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