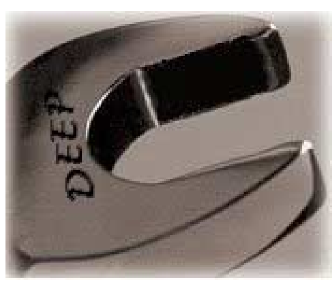
Maintenance Guidelines and Best Practices for Diesel Engines in Underground Mining



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Maintenance Guidelines and Best Practices

Introduction

An improved strategy toward diesel engine maintenance requires not only a firm commitment from management and planners, but an implementable set of best practices that mechanics can adopt into their everyday routine. This guide provides the foundation from which the maintainers of diesel engines can build a system that best suits the needs of their equipment.

A five person technical panel of authorities on maintaining diesel engines has established this guide based on a combination of previous research and individual experience. The following guide is divided into two categories of equal importance. Operational issues target the practices of both mechanics and operators concerning diesel engines. The system specific section targets the six primary engine systems outlined in previous research and expands on improved practices that address the needs of today’s engine technologies.

Operational Issues

Both mechanics and operators share equal responsibility for the proper maintenance of a diesel engine. To maximize the skills of each a process should be implemented that ensures proper training tools, best practices, and proactive attitudes are emphasized and made available.

Training

Training should be approached in a series of short graduated stages for operators and mechanics. Whenever possible both groups should be trained together to promote a better working teamwork between operators and mechanics. It should never be assumed that an operator’s knowledge is restricted to engine operation only. One of the most effective tools a mechanic has is a skilled and knowledgeable operator.

Training courses for mechanics and operators should be in stages based on the six major engine systems.

- Intake System – A short hands on training session that explains the fundamentals of proper filtration, diagnostics and indicators, and design efficiency.
- Exhaust System – A hands on session explaining design efficiency, function vs operation, aftertreatment devices, and maintenance practices.
- Fuel Injection System – A hands on workshop that looks at the different types of fuel systems in use, basic operation, filtration issues, diagnostic basics and the need to avoid complex repair situations.
- Cooling System – Another hands on shop session that looks at basic types of cooling systems in use and operation, basic service practices (cleaning, pressure testing, etc), and diagnostics.
- Fuel Quality and Handling – An especially important session for operators looking at proper storage, transfer, filtration and cleanliness.
- Lubrication System – A hands on session explaining operation fundamentals, oil and filter service practices, and used oil analysis techniques.

Some Do's and Don'ts for effective training sessions

Do's

- Use the shop environment as much as possible
- Involve as much "hands on" as possible
- Keep the groups small whenever possible – 2 to 4 people
- Bring in qualified engine service representatives to conduct training
- Implement and utilize multimedia training aids such as computerized service manuals and help files
- Identify the best people for training – continued knowledge transfer

Don'ts

- Conduct engine maintenance training in stale classroom environments
- Attempt to train everyone at once
- Allow engine sales representatives to conduct training
- Select trainees alpha numerically

Tools

Proper tools are absolutely essential to maintaining diesel engines effectively. The sophisticated technology of today's engines requires equally sophisticated service tools to maintain them. This is not to say however that the new engine technology has replaced the fundamentals of engine maintenance. For this reason the best choice for engine maintenance tools is a balance between fundamental basics and advanced technology.

Fundamental Tools

- The most critical basic tool for engine maintenance is a clean and organized work environment
- A good quality set of pressure and vacuum gauges for measuring intake, oil and fuel pressures
- A manometer for measuring exhaust backpressure
- An infrared hand held temperature probe
- A hand held digital photo tachometer
- A coolant system pressure test kit
- A cylinder compression test kit

Advanced Technology Tools

- The UGAS exhaust gas analysis system used in the DEEP Maintenance Project is an excellent tool for engine diagnostics
- The Detroit Diesel Diagnostic Link is a software based tool that communicates to DDEC engines
- Caterpillar's Electronic Technician is a software based tool that permits diagnostics with CAT electronic engines
- AVL is an electronic tool used for timing mechanically fuel injected engines

Best Practices

The most obvious place to begin with a set of best practices is the preventive and scheduled maintenance systems for diesel engines. A few basic ideas that can be easily implemented:

- It is absolutely essential to have a systematic record keeping, analysis and planning system in place, preferably a computerized maintenance management system (CMMS).
- Utilize an oil analysis program to determine optimum intervals for engine service
- Examine the possibility of splitting the PM intervals between engine systems and vehicle systems. For example the engine could be serviced at 150 hour intervals while the remaining vehicle systems might only be serviced at 250 hours. This could be a method of achieving better attention to detail as well as optimized intervals.
- Examine the fleet profile and optimize the PM schedule to ensure utility equipment doesn't become over serviced at the expense of production equipment being under serviced.
- The service interval for the intake system is probably the most critical point of all, directly affecting engine performance and emissions. Specified intervals for intake systems only go part way to solving this. Vehicle operators must be made part of this process and educated as to the importance of this. They must become stakeholders in the process and become responsible for engine operation and service. When an operator suspects the need for intake service he should be empowered to take the necessary action himself without being influenced by supervision or maintenance personnel.

Engine tune ups are another area where benefits can be gained by a different approach

- Intervals should be determined by engine performance and exhaust emissions only. The UGAS tool is an excellent method of achieving this. Determining tune up intervals on hours leads to poorer engine performance in many cases. An engine that may be performing optimally may be scheduled for a tune up by hours and end up performing less than optimal afterwards.
- Mechanics should be encouraged to use a diagnostic approach to assessing tune ups. Before opening up the engine the mechanic should be trained to look for clues using basic diagnostics such as turbo boost pressure, air/fuel ratio, timing advance, etc.
- Have engine service reps brought in to the shops and train the mechanics hands on in proper tune up techniques.

Major Engine Repairs

- The mine should set up an engine exchange program with each engine supplier. This ensures that the mine receives lowest cost and highest quality service for major engine repairs. Engine suppliers are better trained and equipped to handle these repairs
- Learn to spend that little bit of extra time and effort to maximize diagnostics. Often engines are needlessly opened up due to misdiagnosed problems. Once again this comes back to an effective training program.
- Keep the major engine repairs in the U/G shops to a minimum. This is not an environment that is conducive to complex engine repair procedures. In frame overhauls should be avoided whenever possible in an U/G shop. These practices generally lead to engine replacement shortly afterward due to poor performance and excessive emissions.
- When an engine is changed out the mechanics should be trained to look for damage and possible repairs to auxiliary equipment such as engine mounts and frame, intake system, exhaust system, etc.

Proactive Attitudes

The philosophy of "repair on failure" may provide short term benefits but in the long term proactive engine maintenance delivers cleaner, and more efficient engines that run longer with greater dependability. To succeed in this, operators, mechanics and supervisors must all participate equally in becoming more aggressive in the maintenance of diesel engines.

Operators

- Adopt a program where operators are trained in basic engine maintenance for filter changes and minor repairs
- Through training, heighten their senses toward the relationship between engine operation and maintenance. The best example of this is the smell of engine exhaust fumes at the operator compartment. Instead of waiting until operating conditions become uncomfortable, operators should be trained to sense a problem condition earlier and take corrective action immediately.
- Train them to better understand engines and why conditions occur
- Operators must come to respect the equipment they are in charge of and become accountable for ensuring it's proper operation and maintenance

Mechanics

- Mechanics must learn to respect and LISTEN to operators. There should be a level of communication and understanding established between the two that allows them to work as a team rather than individuals.
- Increase the level of training and motivation for mechanics with a "buy in" approach. Teach them to understand exhaust emissions, and the effects and results of maintaining engines properly on emissions.
- Target the best people for relevant tasks. The best problem solvers should be used for diagnostic situations and their skills used to utmost advantage. By the same token, the person who works full time on the service pit performs an equally important role and should be trained and empowered accordingly.
- Set up a knowledge transfer program where individuals train their peers in an informal hands on environment. This could involve the diagnostic specialist sharing skills with the person on the service pit and likewise vice versa.

Supervision

- Supervision on both operations and maintenance sides play a pivotal role in becoming proactive and empowering the people under their responsibility.
- Leadership for proactive engine maintenance practices comes from the top down and supervision must take the initiative with this
- In this leadership role supervision must ensure that the people are trained in the new approach and thus empowered to implement it.
- It should be the role of supervision to implement regular meetings and a review process of the new engine maintenance process

Engine Systems

The six primary engine systems outlined in previous research remain as valid today as they did twenty years ago. What has changed however is the engine technology as it pertains to each system. The technical panel has revisited these systems and produced a new set of recommendations for each. The systems are listed in order of priority and potential impact to emissions reduction

Intake System

In a mining application the intake system becomes the most critical engine system affecting exhaust emissions. Problems associated with intake air are magnified in every other engine system's performance. Some points worth considering in maintaining intake systems:

- The ducting and piping for the intake system should utilize two spring loaded band clamps at each rubber hose connection
- The entire system, ducting, filter housing, gaskets, etc. should be tested every 100 hours for integrity and leaks. The use of ether spray that was at one time common practice is not recommended under any circumstances due to danger of fire and explosion and possible engine damage. The best alternative is a compressed air charge system described in the next section.
- The location and installation of intake filter housings should be evaluated. Ideally they should be situated away from heat sources (exhaust) and dust sources (tires). They should also be installed to facilitate good serviceability.
- Every underground diesel engine should be equipped with a two-stage intake filter system with a radial type seal at the back of the filter for fail safe protection.
- Inspect intake filter system and verify that it is sized correctly to meet engine requirements. Consult with OEMs and filter manufacturers to obtain this information.
- Verify that ducting is of sufficient size without unnecessary restrictions.
- Ensure that intake filter housing is installed as close to the engine intake manifold as possible.
- On engines equipped with dual intake filters ensure that there is a common connection to both housings to prevent balance problems such as turbo overspeed.
- Do not rely solely on intake restriction indicators located at the filter housing. Proper gauges should be installed at the operator dash. It is imperative that operators be educated on the use and importance of this.
- Intake systems should be serviced at minimum intervals. This would be at least a weekly inspection and possible filter service if required. Once again it is imperative that the operators be educated and empowered to monitor the intake system and make necessary service immediately on detection of a problem.

Servicing The Intake System

Assemble a testing system as shown in Figure 1. The components of the system are:

1. Sealed filter element(s)
2. Air pressure regulator and hose assembly
3. Spray bottle with soap & water solution

Figure 1 - Intake System Testing

The filter elements are easily sealed with Ductape or any other industrial tape capable of sealing less than 5 psi. Any used or dirty element will work fine for this purpose. The intake system does not have to be completely sealed in order to hold a small amount of pressure. Air will still pass by the intake valves and turbo, but the sealed filters are usually enough to hold the low pressure. The regulator and hose assembly can be made up from readily available components found in most underground shops. Ideally a regulator capable of high flow at low pressures such as those used for pneumatic paint spray guns work best. The # 4 hose can be easily adapted to a fitting tee'd in to the intake system. The filter service indicator is usually a good, easily accessible point for the tee. The spray bottle should be approximately 1 liter to hold enough solution to service an entire intake system.

The regulator should be adjusted normally to no more than 5 psi. This is mainly for safety considerations with a pressurized system. The suction side of the intake system between the filter and the turbo should NEVER be pressurized to more than 5 psi for testing. The filter housing, intake piping and hoses are not designed to withstand higher pressures. The pressure side of the intake system between the turbo, air to air coolers and intake manifold can and should be tested at higher pressures up to 25 or 30 psi safely. It is best to pressure test each side of the intake system separately for safety reasons and for verification of proper condition. Check the manufacturer's specification for intake pressure before charging the system to be sure. As shown in Figure 2, spray the solution on all hoses, clamps, connections, flanges, manifolds, and coolers for the intake system. Leaks will appear as bubbles on contact. ***All defects should be repaired immediately and re-tested. This is not a repair that can be scheduled for a later time.***

Figure 2 - Checking Intake For Leaks

Exhaust System

The exhaust system can have a large impact on emissions reduction with relatively minor and basic maintenance practices. Monitoring the physical properties of exhaust such as gas concentrations, pressure and temperature is absolutely essential to proper maintenance.

- Monitor exhaust back pressure at regular service intervals using one or a combination of mechanical gauge, UGAS analysis system, or incorporating back pressure as a DDEC input. Back pressure is a prime indicator of how both the engine and exhaust system are performing with respect to baseline values.
- Inspect the installation of exhaust aftertreatment systems. Verify that they are properly sized (too small OR too big) and that they are close enough to the exhaust manifold for maximum operating temperature.
- Establish a method of evaluating the condition and performance of aftertreatment devices. This can be done by measuring back pressure and gases with tools such as the UGAS system.
- Inspect the installation of the piping on the exhaust system. Look for dents, leaks, damage, and possible causes of restriction that could increase back pressure. When

possible use heat wrap for protection and also to maximize exhaust temperatures for aftertreatment performance.

- Inspect the condition of the turbocharger assembly. When inspecting the fins make sure to look from the top inside and not from the end. Check the compressor wheel on the intake side for a sandblasted effect. Aftercooler pressure differential should be measured regularly to ensure proper cooling. Operators should be trained in the proper operation of turbo equipped engines as to the start up and shut down procedures.

Understanding Exhaust Emissions

EMISSION	***CAUSE***	***TYPICAL LEVEL IN UNTREATED EXHAUST***	***EFFECTS***
Carbon Monoxide (CO)	Product of incomplete combustion of fuel. Usually problems with fuel system (injectors, pump, etc.) or plugged intake.	100 - 400 ppm	Lethal in large doses. Causes headaches and lethargy
Nitrogen Oxides (NOx)	Generated in the reaction between oxygen and nitrogen under high temperature and pressure in the engine cylinder. Usually problems with timing or valve settings.	650 ppm	Creates respiratory difficulties. Partly responsible for smog.
Sulfur Dioxide (SO2)	From sulfur content in fuel.	5 - 50 ppm	Partly responsible for acid rain.
Hydrocarbons (HC)	Unburned components of fuel. Could be derived from any of the conditions described above.	20 - 200 ppm	Responsible for harsh odor and eye / throat irritation.
Diesel Particulate Matter (DPM) Incl. Soluble Organic Fraction (SOF)	DPM is a product of incomplete combustion of fuel. Composed of the solid, visible particulate suspended in exhaust gas SOF: component of DPM hydrocarbons and their derivatives adsorbed on the surface on inorganic carbon (soot) particles. SOF may constitute 30% and more of the total DPM.	5 - 100 mg/m3	The black, blue and white smoke commonly seen in diesel exhaust. Commonly referred to as soot. Suspected to be a human carcinogen.

Exhaust Aftertreatment System Maintenance

Diesel Oxidation Catalysts (DOCs)
These devices are designed to convert carbon monoxide (CO) to carbon dioxide (CO2). In addition, they also reduce hydrocarbons (HC) and the HC fraction of DPM. Diesel oxidation catalysts are very effective due to the excess oxygen present in diesel combustion and the reaction between the oxygen and the catalyst element.

In order for these systems to operate efficiently they must work with exhaust temperatures in excess of 200° C. This requires that the installation of the system be such that the purifier is mounted as close as possible to the exhaust manifold for maximum temperature. It is also important to use low sulfur fuel with DOCs as the catalytic element can be poisoned and neutralized by excess sulfur. It should also be noted that DOCs do not reduce NOx emissions.

To effectively maintain diesel oxidation catalysts the following points should be adhered to:

- Use emissions measurement on a regular basis to calculate CO conversion efficiency. Efficiency should be between 65% to 95%. The formula for efficiency based in percentage is:

$$\left\{1 - \frac{COPost}{CO\,\mathrm{Pr}e}\right\} \times 100$$

- Use exhaust backpressure for monitoring purifier condition. Establish a baseline value for each engine series with a new or clean purifier. Maintenance checks should not exceed 3 i.w.g. above baseline value. Backpressures exceeding this indicate need for service.

- Clean catalytic purifiers using compressed air, steam cleaning, and fuel. After blowing out and washing with steam, soak the purifier in a clean container of diesel fuel, Figure 3, for at least 2 hours to loosen and dissolve hard carbon buildup. After soaking, re-steam and blow out with compressed air.

***CAUTION* When blowing out purifiers with compressed air, ensure the safety of yourself and others with adequate ventilation to avoid exposure to airborne soot.**

Figure 3 - Cleaning Oxy Catalyst in Fuel

Figure 4 - Using a Light To Check For Carbon Buildup

To effectively maintain diesel particulate filters the following points should be adhered to:

- Exhaust backpressure and temperature should be continuously monitored with a permanent on board system including an alarm system to warn the operator. If available, smoke density or opacity measurement systems are useful in determining a pass or fail condition of a particulate filter as well.

- Filters can be cleaned manually using compressed air. Blow out the filter in the reverse and then forward direction of exhaust flow. This can be a very dirty operation and extreme caution should be exercised to avoid exposure to airborne soot. If possible it is a good idea to set up a device for servicing filters that traps the soot in water or another filter mechanism so that it does not get vented to the shop fresh air supply.

- Filters can also be serviced using a kiln or similar controlled heating device. This simulates the thermal regeneration of the filter that is normally done by the engine exhaust temperature. It is important to note that the kiln must support the burning of soot without going into an uncontrolled regeneration condition and have proper environmental controls for safely ventilating and avoiding exposure to harmful compounds.

Fuel Injection System

The fuel injection system is the most complex of all engine systems to maintain. The components are precision engineered with extremely close tolerances. For this reason the basics of maintenance and especially cleanliness are the most important considerations here.

- Check the primary fuel pressure on a scheduled basis. The entire fuel injection system relies on primary pressure for supply and lubrication as well as some cooling functions.
- Examine the filters that are being used and what criteria they are selected on. Price is absolutely NOT the criteria by which filters should be selected for underground diesel engines. Performance and protection are all that matters here. Filters should be OEM whenever possible and should not pass particles larger than 5 microns. There should also be a guarantee that they will not permit the passage of water.
- Verify the proper operation of the air/fuel ratio
- Inspect the fuel lines for proper size, condition and length. Fuel lines should be replaced when required but NEVER repaired.
- Inspect the system for correct match of engine to pump, injectors, lines, etc. Often parts are replaced that are incorrectly matched with the original equipment.
- Fuel temperature should be checked regularly to make sure that it is not becoming overheated. This must be done with the vehicle at maximum operating temperature after several hours of continuous operation. The temperature of the fuel in the tanks should never exceed 60° C.
- Use a filtered vent on the fuel tank. An open vent draws dirt continuously while the engine is drawing fuel. This puts unnecessary reliance on the fuel filters to catch this dirt. The tank breather element should be finer than 5 micron.
- As part of the scheduled maintenance the mechanic should check for air in the fuel in the form of champagne bubbles. Using a plastic hose in-line on the return side of the fuel system can do this. Air bubbles cause problems with injection pressures.
- Adjustments and or replacements of any component such as injectors or pumps should be done only after the need to do so has been verified by testing engine performance and emissions. A systematic diagnostic approach must be taken before any fuel injection component is adjusted or changed. Failure to do so often leads to worse performance than the original condition. A good example of this would be the pop testing of mechanical injectors. Suspicion of an injector problem does not warrant replacement. Testing for chatter, spray pattern, holding and opening pressure, and leaking verifies the need for replacement.

Figure 5 - Testing Fuel Injectors

SYMPTOM

Starting Problem	Engine Surges at Idle	Rough Idle When Engine Is Warm	Engine Misses Under Load	Low Power	Excessive Fuel Consumtion	Engine Cannot Be Shut Off	Poor Performace OR Black Smoke OR Low Power	Fog Like Exhaust In Full Load Range (white or blue)	Incorrect Idle or Maximum Speed	Engine Does Not Rev Up	Injection Pump Runs Hot	CAUSE	REMEDY
•	•		•	•				•		•		Tank empty or tank vent blocked	Fill tank/bleed system, check tank vent
•	•	•	•				•	•		•		Air in the fuel system	Bleed Fuel system, eliminate air leaks
•						•						Shut off/start device defective	Repair or replace
•			•	•				•		•		Fuel Filter blocked	Replace fuel filter
•			•	•			•	•				Injection lines blocked / restricted	Drill to nominal i.d. or replace
•			•	•						•		Fuel supply lines blocked / restricted	Test all fuel supply lines – flush or replace
•			•	•	•							Loose connections, injection lines leaking or broken	Tighten the connections, eliminate the leak
•			•					•		•		Paraffin deposit in fuel filter	Replace filter, use winter fuel
•			•	•	•		•	•		•		Pump – to – engine timing incorrect	Readjust timing
		•	•	•	•		•			•		Injection nozzle defective	Repair or replace
				•	•		•					Engine air filter blocked	Replace air filter element
•												Pre heating system defective	Test glow plugs, replace as necessary
•		•		•	•		•	•				Injection sequence – firing order mismatch	Install fuel lines in the correct order
	•				•				•			Low idle misadjusted	Readjust idle stop screw
				•					•			Maximum speed misadjusted	Readjust maximum speed screw
			•	•							•	Overflow valve defective or blocked	Clean the orifice or replace timing
		•										Delivery valve leakage	Replace delivery valve (max 1 on 4 cyl , 2 on 6 cyl)
	•								•			Bumper spring misadjusted (RS governors)	Readjust bumper spring
				•	•		•	•		•		Timing device defective	R:pair or replace timing device
•		•		•			•			•		Low or uneven cylinder compression	Repair as necessary
	•			•	•	•	•		•	•		Governor misadjusted or defective	Readjust or repair
•	•	•	•	•	•	•	•	•				Fuel injection pump defective, non adjustable	Remove pump and service

Cooling System

Engine cooling systems are relatively basic in design and function, but are often neglected when it comes to routine maintenance. Scheduled maintenance programs should incorporate more points for engine cooling systems especially when it comes to cleaning. Dirt is the primary concern in keeping an engine cooling system running properly at a consistent temperature.

- Have a specified interval for cleaning radiators. This should be incorporated into the operator's education and empowerment as well. The operator should be trained to have a heightened sense of awareness when it comes to such things as engine over temperature.
- A one inch water hose and a good commercial degreaser tends to work much better than a steam jenny or pressure washer
- Use a light to verify that a radiator is cleaned completely through the core.
- Instrument the engine to measure differential temperature across the radiator. This gives an accurate indication of the performance of the cooling system. These points can also be incorporated as DDEC inputs.
- Thermostats should be checked on a regular basis to verify proper operation.
- Pressure test the cooling system on a scheduled basis and verify the correct mixture for engine coolant.
- Verify that the coolant storage system is clean and mixing is being done consistently and carefully.
- Deutz air cooled engines MUST be cleaned at every engine scheduled maintenance interval. Once again it is best to use a degreaser when doing this.
- On Deutz 413 series engines blower speed should be checked regularly for possible slippage as this is driven by oil pressure.
- Deutz engine oil coolers should also be cleaned regularly and checked with a light to verify.
- On all Deutz engines verify that all gauge and alarm sensor wires are connected and in proper operating condition. Check for proper match of gauges to sensors.

Cooling System Maintenance

Daily Maintenance
- Check the coolant level in the top tank or header tank
- Check and clean radiator core as necessary

Monthly Maintenance
- Check the condition and tension of fan belts, adjust and replace as necessary
- Check condition of inhibitors
- Check coolant for proper freeze protection
- Check the condition of gasket in radiator cap

Yearly Maintenance
- Clean the cooling system relief valve
- Drain, flush and clean complete cooling system. Replace with new coolant mixture.
- Check the condition of all hoses and clamps, tighten and replace as necessary

Coolant Mixture
Water alone must NOT be used in a diesel cooling system. Both distilled and softened water are excessively corrosive and lack the proper heat transfer properties as well as freeze protection. It is important to have a consistent and accurate method of mixing coolant for proper protection. Use of ethylene glycol type antifreeze solutions is highly recommended for coolant mixtures. A procedure for premixing and storage of coolant should be used. The solution should be mixed at a level to provide protection that exceeds the system requirements.

Ethylene Glycol % Concentration	Freezing Point	Boiling Point
0% Ethylene Glycol	0°C (32°F)	
20		103°C (217°F)
30		104°C (219°F)
40		106°C (222°F)
50	-37°C (-34°F)	108°C (226°F)
60		111°C (231°F)
68	-54°C (-65°F)	
70		114°C (238°F)
100% Ethylene Glycol	-23°C (-10°F)	

Conditioners and Inhibitors
Conditioners such as Nalcool 3000 should be used on a scheduled basis. These products reduce the risk of rust and pitting to the cylinder liners, block and head. They also reduce the buildup of scale and deposits in the cooling system. Most conditioners will provide protection for seals, hoses, gaskets, and metal materials in the cooling system.

Cleaning and Flushing
The cooling system should be flushed and cleaned at least once a year and also whenever engine repairs dictate. An example of this would be a leaking oil cooler which resulted in oil contamination in the coolant. A simple dishwasher detergent such as Calgon mixed with water works very well in flushing the cooling system. Repeated flushes may be necessary to remove all dirt and oil contaminants from the system. It is very important to make sure that the system is completely cleaned before adding new coolant and conditioners.

Troubleshooting

The first steps in diagnosing an overheating condition are all visual checks. The easiest and most obvious checks are

- Low coolant level
- Loss of coolant – external or internal leaks
- Clogged radiator – check using a light
- Low fan speed – check using a tach
- Fan condition and installation (pushing or pulling)
- Radiator cap seal

If visual diagnostics fail to solve the problem there are some basic tests that can be performed to isolate individual cooling system components.

Thermostats

The thermostats can be tested either in or out of the engine. To test the thermostat without removing it measure the temperatures at both the top tank and stat housing. Observe the level and flow of coolant in the top tank and temperatures as the stat begins to open and circulate coolant through the radiator. This test is only accurate with engines using no more than one thermostat. A more accurate test method is to remove the thermostat and suspend it in a metal container of water. Using an acetylene torch and thermometer heat the water in the container and observe the opening temperature compared to the plug in the stat.

It is important to note that an engine should NOT be run without the thermostats installed. Coolant does not flow properly through the radiator without the thermostat and results in increased overheating.

Aeration in Coolant

The most common cause of aeration is combustion leaking into the coolant. The best way to test for this is to tap a hose from the radiator cap relief valve into a container of water. Bring the engine to full operating temperature and check for steady bubbles coming out of the end of the hose. Sources of combustion in the coolant can be leaking head gaskets, loose head, defective seal, etc.

Radiator Cap Relief Valve

Cooling system pressure can be tested either with a hand pressure pump tool or air regulator and pressure gauge. Pressurize the system to a level just below relief pressure and observe how the system holds pressure. Rapid leakdown indicates either and external/internal leak or leaking relief valve. Pressurize the system higher to determine the relief opening pressure for proper setting.

PROBLEM	CAUSE
Low Coolant Level	❑ External leaks caused by loose / worn hoses, radiator cap, or defective relief valve ❑ Internal leaks caused be cracked cylinder head, cracked block, loose heads, damaged cooler core, damaged aftercooler, damaged gaskets
Reduced Air Flow Through Radiator	❑ Plugged radiator core ❑ Damaged or bent fins ❑ Low fan speed due to idle settings ❑ Fan damaged or incorrectly installed ❑ Loose fan belts, worn pulleys ❑ Damaged fan shroud, incorrect fan ❑ Incorrect fan blade / shroud position – 50% projection ❑ Excessive fan blade / shroud clearance – 0.38" max ❑ Closed shutters ❑ Fluid coupling or clutch not engaged
Low Cooling System Pressure	❑ External / Internal leaks ❑ Defective radiator cap gasket ❑ Defective cooling system pressure relief valve ❑ Defective radiator top tank neck ❑ Defective pressure gauge
Coolant Overflow	❑ Air in cooling system due to incorrect system fill ❑ Combustion gases in cooling system ❑ Steam in system due to overload or low level
Insufficient Coolant Flow	❑ Stuck thermostat ❑ Absence of thermostat ❑ Low engine speed – High idle ❑ Loose or eroded water pump impeller ❑ Radiator plugged internally
High Intake Air Temperature or Restriction	❑ High ambient air temperature ❑ Plugged openings in screens for engine compartment with a blower fan ❑ Dirty aftercooler core ❑ Plugged air cleaner ❑ Damaged or carbon packed turbocharger
Low Heat Transfer	❑ Insufficient flow through heat exchanger ❑ Hot air for radiator due to overheating hydraulic oil cooler ❑ Scale on cylinder liners or cylinder head ❑ High ambient air temperatures with a marginally sized radiator
Exhaust Restriction	❑ Plugged air cleaner ❑ Damaged turbocharger ❑ Restriction in exhaust pipes ❑ Plugged aftertreatment device ❑ Excessive elbows, piping, etc.

Fuel Quality and Handling

An education and awareness program for fuel handling can be easily implemented at any mine. It is important that responsibilities be delegated to ensure that this basic area is consistently addressed.

- Always use high quality low sulfur fuel less than 0.05% (500 ppm) by volume. The fuel should be tested regularly for quality assurance.
- Put together a team responsible for efficient identification, transportation, and handling of fuel. This would involve everyone from supplier, service and shaft crews, to operators and mechanics. Responsibilities should be assigned to specific groups and a scheduled program put into place to ensure that it is carried out.
- Bulk storage tanks should be equipped with water separators and filtered vents. A regular maintenance program should be implemented to make sure they are cleaned and serviced properly.
- Cubes that are used for transporting and storing fuel should be cleaned and serviced on a scheduled basis.
- Vehicle storage tanks should also be equipped with filtered vents and water separators. The fill necks on the tanks should be equipped with strainers or even better, with a quick connect fill system to prevent dirt from entering the system. The fuel tanks should be incorporated into the scheduled maintenance program as well.

Lubrication

Engine lubrication often requires more attention to detail. It is not merely a matter of topping up oil levels or replacing oil and filters. Mechanics and operators both need to recognize this as an important factor in engine maintenance rather than a mundane task.

- As with the fuel filters, engine oil filters are not an area that should be guided by a price factor. Whenever possible OEM filters should be purchased for each type of engine.
- Inspect and evaluate the system for selection, storage, handling and dispersing of lube oils. This should go from the bulk storage system right down through the use of portable containers in the field. Fill cans and nozzles should be checked regularly for cleanliness
- Evaluate the system in place for monitoring oil contamination. Ensure that the information is being used effectively with the right people. Periodically the oils should be checked for reserve alkalinity and soot level to verify the interval baseline.
- When possible install warning systems for engine oil lube temperature. Excessively high temperatures have a direct negative effect on lubricity and viscosity.
- Educate both operators and mechanics on the importance of maintaining and verifying *CORRECT ENGINE OIL LEVELS* in engines.
- Oil and fuel filters should NOT be pre filled on a workbench before installation due to the possibility of unnecessary contamination.

Engine lube oils and their classifications are often disregarded or misunderstood. For mining diesels only the oil meeting the engine manufacturers specified API classification should be used. Failure to do so could result in violation of the CANMET or MSHA certification as well as engine warranty. As technology advances many new lubrication products become available, often for specialized applications. The American Petroleum Institute (API) has had a classification system in place since 1970 as a recognized standard for matching lubricants to proper applications.

- "S" or "Service is the classification for gasoline engines
- "C" or "Commercial" is the classification for diesel engines
- The second letter in the classification designates the time frame

Classification "Service"	**Application**	**Meets OEM Requirements for:**
SA	Formerly Utility Gasoline and Engine Service	Pre – 1930s
SB	Minimum Gasoline Engine Service	1930
SC	Gasoline Engine Warranty Maintenance Service	1964 – 1967
SD	Gasoline Engine Warranty Maintenance Service	1968 – 1971
SE	Gasoline Engine Warranty Maintenance Service	1972 – 1980
SF	Gasoline Engine Warranty Maintenance Service	1980 – 1988
SG	Gasoline Engine Warranty Maintenance Service	1989 – 1993
SH	Gasoline Engine Warranty Maintenance Service	1994 – 1997
SJ	Gasoline Engine Warranty Maintenance Service	1998 – Present

Classification "Commercial"	**Application**	**Meets OEM Requirements for:**
CA	Light to moderate duty, high quality fuels	MIL-L-2104A; 1954
CB	Light to moderate duty, lower quality fuels	1955 – 1963; high sulphur fuel
CC	Moderate to severe duty diesel and gasoline	MIL-L-2104B; 1964
CD	Severe Duty Diesel	Cat certification req's 1955
CD-2	Severe duty 2-stroke engine service	Detroit Diesel 2-stroke and Cat 4-stroke (obsolete)
CE	Severe duty diesel service	Cat / Mack / Cummins 1983 and high speed operation prior to 1980
CF-4	Severe duty direct injected diesel service	Direct injection 4-stroke engines in high speed operation prior to 1990
CG-4	Severe duty diesel engine service	High speed, 4-stroke engines since 1995
CH-4	Sever duty diesel engine service	High speed, 4-stroke engines since 1998

Combined Service Applications

- Used to distinguish the oil as suitable for any engine application (diesel or gasoline) that requires a high level of oxidation stability, better control over sludge, deposits, and acid formation
- The most recent combined classification is : API SJ / CH-4
- These oils are formulated to provide engine protection under the most severe conditions

Acknowledgements

The Diesel Emissions Evaluation Program (DEEP) gratefully acknowledges the participation and contributions of the many individuals and companies that have provided knowledge and materials for assembling this document.

The foundation for this document was established by a technical panel assembled specifically for this project to establish guidelines and best practices for diesel engine maintenance in underground mining applications. The members of this panel are:

Mike Meadows – Detroit Diesel Canada

Gaston Auclair – Deutz Canada

Bob Huzij – INCO Limited

Barry Huston – Williams Operating Corporation

Sean McGinn – Noranda Technology Centre

The following manufacturers and companies have provided reference materials and information included in this document:

Engine Manufacturers

Detroit Diesel Corporation

Deutz Corporation

Caterpillar Inc

Exhaust Aftertreatment and Control Manufacturers

DCL International

ECS – Engine Control Systems

Other

Fluid Life Corporation