DIESEL EMISSIONS

MECHANICS' MAINTENANCE MANUAL

Acknowledgments

This manual was prepared with the intent to provide mechanics and operators of diesel engine equipment with a set of guidelines for an introduction to the maintenance of diesel emission systems. Workshop training sessions will accompany this manual.

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Mechanics Diesel Emissions Maintenance Manual

Introduction

With the continuing increase in environmental and health concerns, there has been growing trend to cut down on the release of any unnecessary exhaust gas pollutants into the environment. Regulations are in place limiting the maximum pollutant concentrations in diesel engine exhaust gas. Furthermore, sufficient ventilation must be provided in order to ensure that pollutant levels in the working environment don't exceed Threshold Limit Values (TLV). This manual has been developed to address these issues from a maintenance perspective. To better understand the relationship between engine maintenance and engine emissions, it's important to know the factors which affect the formation of the exhaust gas components.

Experience has shown that emission characteristics remain constant during the life of the diesel engines, providing that maintenance is performed in accordance with manufacturers' recommendations. Improper or insufficient maintenance will have a negative effect on the combustion process and lead to accelerated wear of engine components resulting in an increase in emissions. This usually occurs before a decrease in performance becomes noticeable.

The traditional approach towards maintenance operations was to look at it as an expensive exercise not yielding any direct benefit. A piece of equipment will be repaired if and when it fails, not before. This type of approach doesn't make sense from an economical standpoint. Timely maintenance extends the life of the equipment, increases the machine's availability for production, and reduces operating cost. Purchasing and operational cost calculations can easily prove the benefits of timely preventive maintenance.

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.

The following guide is divided into two categories of equal importance. Part I (Operational Issues) targets the practices of both mechanics and operators concerning diesel engines. The system specific section (Part II) targets the six primary engine systems outlined in previous research and expands on improved practices that address the needs of today's engine technologies.

Part I

Operational Issues

Both mechanics and operators share equal responsibility for the proper maintenance of a diesel engine. To be effective in this task, they need proper training, good tools, knowledge of best practices, and proactive attitudes.

The mechanics should be introduced to the new tools through a training strategy that should include engine manufacturers training representatives. The primary level of training should be done on a one-to-one basis between the mechanic and the trainer. To complement this, group-training sessions should be conducted with small groups of four to five mechanics. Service representatives should provide training on the various engine systems. During each training session the mechanics will be shown how to incorporate the new process and new tools along with the training to improve performance and reduce emissions.

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:

Record Maintenance

- It is absolutely essential to have a systematic record keeping, analysis and planning system in place, preferably a computerized maintenance management system (CMMS).
- At the first level of monitoring diesel exhaust emissions, the following recommendations for documenting diesel engine maintenance should be adopted. Put together team focused on implementing an improved maintenance strategy. The team should have members including mechanics, operators, supervision, planning, and management from within the organization. Responsibilities should be delegated according to an implementation plan and followed up through a report and meeting structure. Ensure that sufficient resources are made available to the team with respect to time, tools, and training.
- Assemble an engine maintenance audit program using the model in this section of the manual as a template. A good audit program has to have follow-up mechanisms built into it and should be conducted annually. Use the Guidelines and Best Practices included in this manual along with the six system approach to engine maintenance as a foundation in building a strategy for improving existing maintenance practices.
- The program should include testing undiluted tailpipe emissions. Integrate the program into a computerized maintenance management record and planning system. Set action limits on emissions within the system to ensure response to problems. In order to be useful the emissions must be compared against a known baseline. The following chart is an example of how records could be collected and documented.

Test	Desc	O2	CO	CO2	NO	NO2	Smoke	DPM
		%	ppm	%	ppm	ppm	index	mg/m3
1	UPSTR-Pre Mtce	7.49	590.06	9.90	653.28	13.80	9	61.67
2	DNSTR-Pre Mtce	9.56	36.27	8.39	424.37	10.29	9	69.17
3	UPSTR-Mid Mtce	9.01	302.67	8.81	514.59	15.11	9	25.83
4	DNSTR-Mid Mtce	11.85	11.82	6.71	341.75	6.59	9	30.83
5	UPSTR-Post Mtce	10.56	203.30	7.65	467.41	21.91	9	29.17
6	DNSTR-Post Mtce	12.35	35.36	6.34	384.07	9.53	9	34.17

Maintenance Scheduling:

- Utilize an oil analysis program to determine optimum intervals for engine service. An excellent program to use is the CAT SOS oil analysis program available from your local CAT dealer

- Examine the possibility of splitting the P.M.(Preventive Maintenance) 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 (Preventive Maintenance) 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 able to take the necessary action himself. For a detailed explanation of how to properly service an air intake system refer to the section that deals with the six engine systems page 12 .

Engine Tune Ups

- Intervals for engine tune-ups should be determined by engine performance and exhaust emissions . The UGAS tool is an excellent method of achieving this. Setting tune-up intervals on the basis of hours lapsed since the last tune-up 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 more poorly afterwards.

- Have engine manufacturer service reps brought in to the shops and train the mechanics hands on in proper tune up techniques.

- Mechanics should be encouraged to use a diagnostic before starting tuneups. 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.

Major Engine Repairs

* The mine should set up an engine exchange program with each engine supplier. This ensures that the mine receives the 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.

Example: A compression test taken on a diesel engine showed two pistons were low in compression. The cylinder head was removed. Once the head was removed it became apparent that the valves and rings were not the problem. The problem turned out to be a tight exhaust valve on both cylinders. Before any major dismantling occurs, you must follow a best practice troubleshooting procedure, which would have indicated that the valves need to be checked before a compression test is performed. This is a good example of how improper diagnostic procedures will lead to needless repair work.

* Keep the major engine repairs in the underground 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 underground 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

- Operators should be trained in basic engine maintenance in order to perform filter changes and minor repairs.
- Operators should be trained to use their senses to detect potential engine problems, which require maintenance. A good example of this is the smell of engine exhaust at the operator compartment while operating the equipment.

Example 1:
The operators will quickly recognize an abnormal exhaust odour from the exhaust. After performing his initial checks on the intake and exhaust systems and not finding anything abnormal, he would report the change to the maintenance department for further investigation.

Example 2:
While operating his equipment the operator notices that the operating temperature of the engine is slightly higher than normal, but not high enough to warrant a shutdown or activate the warning system. After performing an initial check on things like coolant level, radiator condition, water pump and fan drive systems, he would report the problem to the maintenance department for further diagnostics.

Operators must be held accountable for the condition of the equipment they are operating, and be accountable for ensuring its proper operation and maintenance.

Mechanics

- Mechanics must communicate with equipment 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.

- Training sessions on basic maintenance practices and emissions as they relate to health need to be set up so that the operators and mechanics are both there.

- Increase the level of training for mechanics with a "buy in as related to health matters" approach.

- It is important that mechanics understand the effects of diesel emissions on their own health and that of the operators, as well as the results of proper maintenance 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 in maintaining the equipment in good operating condition and should be trained to perform the necessary service and repairs when required.

- Set up a knowledge transfer program where individuals train their peers in informal hands-on environment. This could involve the diagnostic specialist sharing skills with the person on the service pit and vice versa. This training will take place at the same time as the training on emissions as related to health issues.

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 operating and maintenance people are trained in using a proactive approach and thus are empowered to implement the appropriate procedures to correct poor practices.

- It should be the role of supervision to implement regular monthly meetings with the maintenance personnel to review new engine maintenance techniques.

Typical Exhaust Gas Components:

Carbon dioxide ($C0_2$): Although this gas is non-poisonous, it may still be considered a problem, especially if it is produced in large enough quantities to displace oxygen in the working environment

Carbon monoxide (CO): CO is the result of the incomplete combustion of the fuel, caused by localized insufficiencies of oxygen (rich fuel/air ratio). Quenching of the reaction by cold combustion chamber walls also increases the CO levels. (Example: cold engine operating temperatures) CO gas is a colourless, odourless, and tasteless gas. Inhalation of as little as 0.3% by volume can cause death within 30 minutes. For this reason, it is important never to allow the engine to run in enclosed spaces such as a closed garage without good ventilation. Increased CO concentrations may be the result of poor mixture formation caused by a defective injection system, injectors with defective spray characteristics, or engine over-fuelling.

Oxides of nitrogen (NOx): The formation of NOx is dependent on the temperatures during the combustion process, the concentrations of the components nitrogen (N_2) and oxygen (0_2) and the time available for them to react with each other. NO and NO_2 are generally lumped together and referred to as oxides of nitrogen (NOx). A rise in the combustion temperature increases the NO concentrations in the exhaust gas In a diesel engine, the combustion process forms only NO, a small portion of which oxidizes to $N0_2$ at lower temperatures and in the presence of 0_2. The sum of NO and $N0_2$ is called NOx. These gases belong to two different classes. Nitrogen monoxide (NO) is a colourless, odourless, and tasteless gas that is rapidly converted into nitrogen dioxide (NO_2) in the presence of oxygen - O_2. Advanced injection timing can cause an increase of NO in the exhaust gas. Measures which decrease the NO concentrations, such as low compression ratio or retarded injection timing, also tend to decrease the efficiency of the combustion process. This can result in increased fuel consumption and higher CO and HC concentrations in the exhaust.

Hydrocarbons (HC): HC in exhaust gases is usually from very small quantities of unburned diesel fuel and engine lubricating oil. Since the measurement of concentrations of different hydrocarbons involves the use of sophisticated instrumentation, only total HC is usually measured and reported. In the presence of nitrogen oxide and sunlight, hydrocarbons form substances, which irritate the mucous membranes. Some hydrocarbons are cancer-causing. Incomplete combustion in a diesel engine produces unburned hydrocarbons. Increased HC levels in the exhaust gas are found when an diesel engine suffers from high oil consumption, a defective injection system, rich fuel/air ratio, or quenching of the combustion process in the proximity of the cold combustion chamber walls.

Particulate matter (PM): These include all substances (with the exception of water) which under normal conditions are present as small solid or liquid particles in exhaust gases. PM is usually defined as "any material, other than water, in the exhaust of a diesel engine which can be filtered after dilution with ambient air". These particulates normally consist of a mixture of carbon (soot), hydrocarbons and sulfuric acid. Therefore we can assume that conditions, which affect the formation of soot, hydrocarbons and oxides of sulfur, will affect the particulate emission.

Oxides of Sulfur (SOx): The SOx formation is caused by the oxidation of the sulfur contained in the fuel with the 02 available in the combustion air. The SOx concentrations depend on the sulfur content of the diesel fuel and the fuel consumption of the engine. SOx reductions in the diesel exhaust gas can only be achieved through the use of low sulfur fuels .

Smoke: Smoke is usually defined as solid and liquid particles suspended in diesel exhaust gases, which obstruct, reflect or refract light. Smoke from diesel exhaust can be placed into 3 groups depending on the appearance under direct illumination:

- **Grey/black smoke** consisting of solid particles of carbon, i.e. soot.
- **White smoke** usually caused by the presence of vaporized and unburned diesel fuel in the exhaust gas, example, a misfiring cylinder.
- **Blue smoke** is usually caused by high concentrations of unburned or partially oxidized fuel or lubricating oil in the exhaust gas. This situation is typical of a diesel engine operating at low temperatures or suffering high oil consumption.

The visual appearance of the exhaust gas will depend on, the type of illumination and the background against which the exhaust gas is observed. In general, the "colour" of the exhaust gas will appear as white/bluish, or grey/black.

The diesel exhaust gas odour is a result of a combination of aromatic hydrocarbons and other substances such as aldehydes. Since "odour" cannot be described objectively, conditions affecting the formation of odour-causing compounds are not easily well defined. However, for a given diesel engine, conditions which may affect the concentrations of unburned HC will tend to affect the odour of the diesel exhaust gas.

Engine Systems and Conditions That Affect Diesel Emissions:

There are many different factors that affect the formation of the exhaust gas components.

These include:

- **Combustion Chamber Design**
- **Intake Manifold System**
- **Operating Conditions that Affect Emissions**
- **Low Turbocharger Boost Pressure**
- **High Exhaust Back Pressure**
- **High Crankcase Pressure**

Combustion Chamber Design:

Since the invention of the diesel engine, many different diesel combustion systems have been developed. Some of these systems were designed to maximize fuel economy, improve cold start ability, or reduce noise. Other types of designs obtain the best possible exhaust emissions. There are many trade-offs between fuel economy and emissions.

Combustion systems can be classified into two classes, direct Injected (D.I.) or indirect injected (I.D.I.) D.I. systems provide the best fuel economy I.D.I. systems are better at reducing harmful diesel emissions.

Direct Injection Systems

The two main advantages to the open combustion chamber design of D.I. (Direct Injection) are its simplistic design (over all cheaper to produce) and its high fuel economy. This design had a down side to it when fuel injection systems were mechanical, and had static timing. They tended to produce higher emissions that I.D. injection systems. That is no longer the case with modern electronically controlled injection systems, which have variable timing.

Fig. 3-1 Direct Injection System

Indirect Injection Systems:

In mechanical fuel injection systems I.D.I. (Indirect Injection) systems have a separate pre-combustion chamber which allows the combustion process to be slowed down during the power stroke. There is a limited amount of oxygen in the pre-combustion chamber, which would not allow the fuel to ignite completely, resulting in a partial burn. As the piston moves down on the power stroke it would draw the contents of the pre-combustion chamber into the main chamber where there is more oxygen causing the partially burned fuel to burn rapidly in the main chamber. This controlled burn results in a more complete combustion process, resulting in lower overall emissions.

For any diesel engine, the emission concentrations are a direct relation of engine speed and load, ambient temperature conditions, and fuel quality.

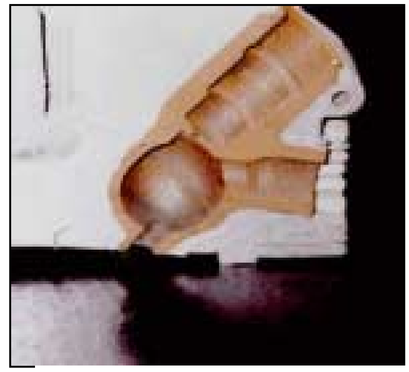

Fig. 3-2 Indirect Injection System

Intake Manifold System:

The induction system is designed to supply clean, dry air to the engine, with as little restriction as possible. A properly designed system must be able to withstand shock loadings along with a wide range of working conditions as encountered in actual service. The intake system must provide reliable system sealing and durability. Diesel engines operate with a high fuel/air ratio. Excess air is always present during the combustion process and in the exhaust gas.
The most critical operating conditions are full load, or full fuel operation. Every engine manufacturer prescribes the maximum intake restriction which is allowed for a given engine family when operating at rated conditions. If the induction system was properly laid out during the installation of the engine into the equipment (air cleaner, hoses, pipes, etc. of proper size and flow characteristics), insufficient combustion air would not be a problem. Every diesel engine will react differently, depending on the combustion system and the overall condition of the engine. Generally, a system that was not laid out properly can easily be recognized by the excessive black smoke given off.

A failure of a combustion air intake system component such as the filter element, or a hose or clamp, will allow dust-laden air to by-pass the air cleaner and get into the engine. Such a condition is a serious problem when the engine is operating in a dusty environment. Depending on the type of dust contained in the combustion air and its abrasive properties, accelerated wear of the intake valves, pistons, piston rings and cylinders can occur, resulting in increased oil consumption and blow-by up to a point where compression is lost and horsepower reduction occurs. This process leads to an increase in emissions. The rise in oil consumption always results in increased HC (hydrocarbons) and odour, followed by higher CO (Carbon Monoxide) concentrations.

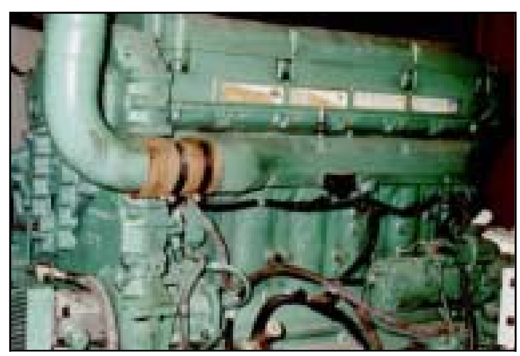

Fig. 3-3 Intake Manifold System

Operating Conditions That Affect Emissions:

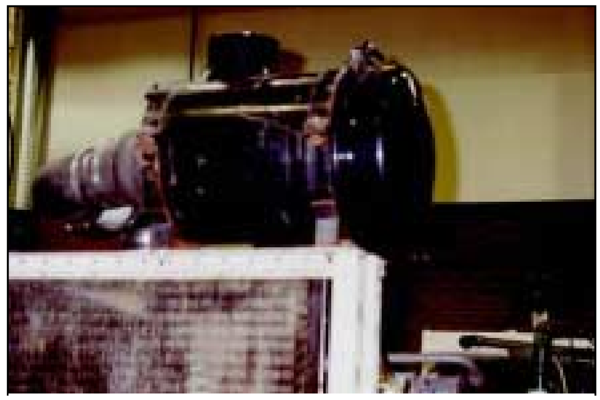

Fig. 3-4 Typical Air Filter Installation

- Plugged or dirty pre-cleaner or main element air cleaner (pre-cleaner or the main element)
- Too small an air filter assembly. Improperly sized to pass the required amount of air. Check the filter manufacturer's recommended Cubic Feet per Minute Rating (CFM).
- Intake piping diameter too small. Check the engine manufacturer's minimum and maximum intake pipe diameter and length.
- Intake piping too long. Check the engine manufacturer's minimum and maximum intake pipe diameter and length.
- Intake piping contains too many elbows or bends. Check manufacturer's recommendations as to the number of bends allowed in a given length of piping.
- Visually inspect for crushed or damaged intake piping.
- Damaged or bent housing on air cleaner assembly.
- Collapsed rubber hoses in intake piping.
- Water-soaked paper filter element. Employ a moisture eliminator assembly when operating in heavy rainfall and high humidity areas.
- Dust plugging leads to short filter life. Use two-stage filters and exhaust gas aspirators.

Low Turbocharger Boost Pressure:

There are many causes for low turbocharger boost pressure. Turbo-boost pressures are similar for two- and four-stroke-cycle engines. Strategically placed small pipe plugs on the engine can be accessed to isolate the Turbocharger boost pressure from the air box pressure on two-cycle engines such as the Detroit Diesel 2 stroke models.

Fig. 3-5 Typical Exhaust System

Some of the reasons for low boost pressure can usually be traced to the following conditions:

- A high exhaust back pressure condition. (Check for plugged or restricted after treatment devices or exhaust deflectors)
- Exhaust gas leaks feeding to the turbo from the engine. (Check for telltale signs of black soot around turbo exhaust connections.)
- Leaking fittings, connections, or intake manifold gasket from outlet side of turbo (usually accompanied by a high-pitched whistle under load due to pressurized air leaks)
- Plugged turbocharger safety screen if used on the inlet or outlet side. Plugged or damaged air system after-cooler. (Check the temperature drop across the aftercooler. Refer to manufacturer's specifications for your particular application.)
- Possible turbocharger internal damage (check the condition of the turbine and compressor vanes for damage with the engine stopped)
- Leaking gasket between direct-mounted Turbocharger and the blower housing on a Detroit Diesel two-cycle engine
- Low air box pressure on a two-cycle Detroit Diesel engine caused by any of the following conditions: leaking inspection covers on the block, leaking cylinder block-to-end-plate gaskets, a plugged blower inlet screen, or a partially stuck closed emergency air system shutdown valve

High Exhaust Back Pressure:

The exhaust system must be laid out in such a manner that the maximum permissible exhaust backpressure, as prescribed by the engine manufacturer, is not exceeded. A slight backpressure (refer to manufacturer's recommendations for maximums, generally no more than 25 inches of water) in the exhaust system is normal, but excessive exhaust backpressure will affect the operation of the diesel engine. The use of after treatment devices such as catalytic converters, flame arrestors, water scrubbers, or particulate traps will increase the engine exhaust backpressure. Excessive exhaust backpressure has a similar effect on engine performance and emissions as an intake restriction. Power output reduction and increased exhaust temperature will become a problem. CO, black smoke and particulate emissions will also go up, counteracting the effect of the after treatment device. Improper maintenance could lead to plugging up the after treatment device and create a flow restriction in excess of the manufacturer's recommended limits.

Here are some typical causes of high exhaust backpressure:

Fig. 3-6 Damaged Exhaust System

- Rain cap stuck at the end of a exhaust stack
- Crushed exhaust piping
- Crushed or damaged muffler
- Too small a muffler. Refer to manufacturer's recommended muffler size for a given engine.
- Exhaust piping diameter too small. Check the filter manufacturer's recommended CFM (Cubic Feet per Minute Rating)
- Exhaust piping too long. Check the engine manufacturer's minimum and maximum intake pipe diameter and length.
- Exhaust piping with too many elbows or bends. Check manufacturer's recommendations as to the number of bends allowed in a given length of piping.
- Excessive carbon build-up in exhaust system. Check the exhaust backpressure using a manometer. Refer to manufacturer's recommendations for a given engine size. If excessive, remove and clean after treatment devices.
- Obstruction in exhaust system or piping.

High Crankcase Pressure:

All Diesel engines operate with a slight crankcase pressure (1 to 3 inches of water) which is highly desirable since low pressure prevents the entrance of dust and keeps any dust or dirt suspended in air so that it can flow through the crankcase and be trapped in the engine breather system. If there are signs of engine lube oil coming from the engine breather tube, crankcase ventilator, dipstick tube hole, crankshaft oil seals, or air box, drain tubes on two-cycle Detroit Diesel Engines. This may be a positive indicator of high crankcase pressure. Refer to manufacturer's recommended maximum backpressure allowed for a given model of engine.

Fig. 3-7 Crankcase Breather

Proper lubrication, the use of adequate grade oils, and regular oil change intervals minimizes wear and ensures long engine life and stable exhaust emission quality. Failure to follow manufacturer's recommended oil grades will accelerate engine wear, increase lube oil consumption and have a negative effect on exhaust emissions. Increased engine blow-by, higher HC concentrations and visible blue or black smoke in the exhaust gas will become noticeable prior to performance deterioration.

Causes of high crankcase pressure can usually be traced to the following conditions:

- Too much oil in crankcase (check oil level).
- Restricted crankcase breather (Check engine crankcase back pressure to see if it is above manufacturer's recommendations.)
- Higher than normal exhaust backpressure (Check exhaust back pressure to see if it is above manufacturer's recommendations.) (restriction in the after treatment devices)
- Excessive cylinder blow-by (caused by worn rings, scored liner, cracked piston, or a hole in a piston).

Part II

Overview of the Six Engine Systems:

Introduction:

This Section presents an overview of the six engine systems, the factors affecting exhaust quality, and how proper engine preventive maintenance can ensure long diesel engine life. Improper, insufficient or lack of preventative maintenance will lead to accelerated wear of engine components. This will result in an increase in emissions usually before a decrease in performance becomes noticeable.

Lack of proper maintenance, failure to follow manufacturer's recommendation or abuse of the equipment, will lead to accelerated wear, decreased performance, excessive oil consumption and increased Hydrocarbons (HC), Carbon Monoxide (CO), Oxides of nitrogen (NOx), and Oxides of Sulfur (SOx) emissions.

1) INTAKE
2) EXHAUST
3) FUEL INJECTION
4) COOLING
5) FUEL QUALITY AND HANDLING
6) LUBRICATION

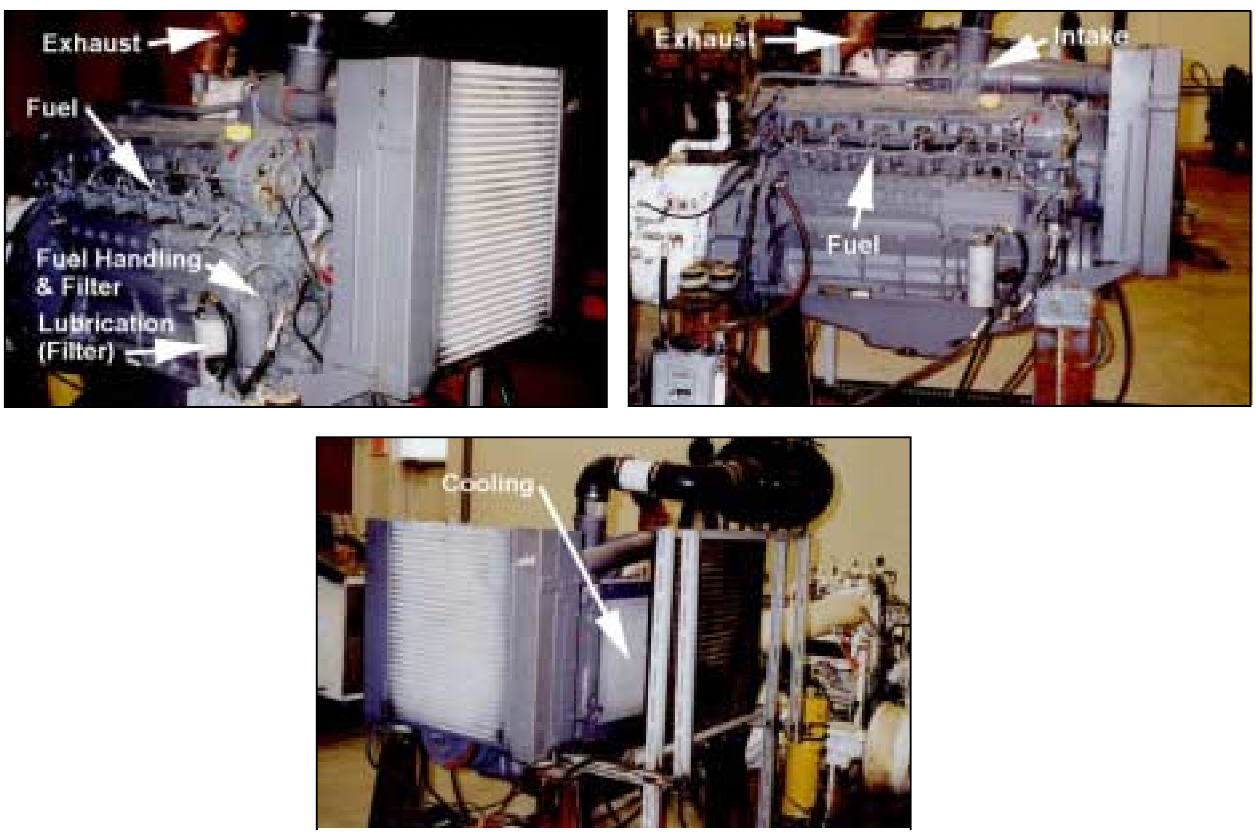

Fig. 4-1 A Diesel Engine and Components

1. Intake System:

Introduction

The intake system on a diesel engine must provide an adequate supply of clean air for good combustion at all operating speeds, loads, and operating conditions. As much as 1500 cubic feet of air per minute or more may be required. This depends on engine size and horsepower. On naturally aspirated (non-turbocharged) and turbocharged engines, air is as important to good operation as the quality of the fuel used. Lack of adequate airflow to an engine can result in high emissions along with poor performance

Contaminated air can quickly wear out a diesel engine - a condition often referred to as "dusting". This condition is particularly noticeable when an engine has been overhauled, and after a short period in service, compression and power losses are noticeable.

Fig. 4-2 Typical Intake System

Tests conducted by major diesel engine manufacturers have shown that as little as two tablespoons of dirt can dust out an engine within a very short time. Unfiltered air contains small particles of dirt and abrasive material that are not always visible to the naked eye.

Intake air can also be contaminated by partially burned fuel. Some of it washes down the cylinder wall and can dilute lubrication oil. Some of the unburned fuel dries up and sticks to pistons, rings, and valves as well as fouling up the small orifices in the injector tip, resulting in higher emissions. Nothing wears out a diesel engine faster than contaminated air entering the intake system. The dirt and oil mixture acts as an abrasive lapping compound. On the cylinder walls it proves to be disastrous. Imagine how the continuous rubbing action of the piston rings against the liner surface contaminated with abrasive dirt in the oil quickly accelerates wear.

The air cleaner on diesel engines is designed to remove moisture, dirt, and dust from the air before it reaches the engine. It must do this over a reasonable time period before servicing is required. The air cleaner also acts as a silencer to reduce intake air noise. On a turbocharged engine, additional air is supplied by means of a turbocharger, which is exhaust gas driven On a supercharged engine (Detroit 2 cycle) a mechanically driven blower is used to supply additional air. The filter sizing should take into consideration these two additional features. **(Always refer to the manufacturer's recommended filter sizes for any given engine application.)**

Fig. 4-3 A Two-Stage Intake system

Dry Type Air Cleaners:

Modern dry-type air cleaners may have one or more replaceable filter elements and may include primary and secondary or safety filtering elements. Most dry-type air cleaners also include vanes, which act as a type of pre-cleaning device. The vanes may be part of the filter element or they may be part of the air cleaner housing. As air enters the air cleaner, it passes over the vanes, which impart a swirling action to the air. The swirling action causes the heavier dust and dirt to be thrown outward by centrifugal force against the air cleaner housing, where it goes to the dust collector.

Fig. 4-4 Typical Intake System with TBS

The air intake system on modern electronically controlled diesel engines is equipped with one or more of the following sensors: ambient air pressure sensor for altitude compensation, intake manifold temperature sensor, and turbocharger boost pressure sensor. Any of these sensors can quickly detect a problem and cause the engine ECM (Electronic Control Module) to compensate by reducing the amount of fuel that is available thereby reducing speed and power. These sensors are normally located on the intake manifold.

Air Induction Piping:

The air induction piping works with the air cleaner to carry clean filtered air into the diesel engine. When you service the air cleaner filter assembly, it is extremely important to check the piping hoses, elbows, and clamps for looseness, tears, or ruptures. Ignoring these can lead to unfiltered air entering the system and destroying the engine in a very short time. Inspect the intake ducting (piping) and elbows every time you service the air filter.

Fig. 4-5 Air Induction Piping

Aftercoolers:

On electronically controlled high-speed heavy-duty diesel engines one of the most important components in use today is the turbocharger pressurized-air aftercooler. Ideal air temperature for modern turbocharger diesel engine is usually in the region of 35 to 38°C (95 to 100°F).The higher the ambient air temperature, the greater the expansion of the air, the greater the loss of engine power . Depending on the rise in ambient air temperature and the diesel engine design features, an engine can lose between 0.15 and 0.7% horsepower per cylinder for every 6°C (10°F) rise beyond 32°C (90°F), or approximately 1% power loss for each 6°C (10°F) of intake temperature rise above 32°C (90°F).

Fig. 4-6 Typical Aftercooler

Air-to-Air Aftercoolers:

The most efficient and widely used turbocharger boost air aftercooler for heavy-duty applications is the AAAC, or AAAAC as some engine manufacturers refer to it. Since cooler air is denser, a greater amount of air is in fact supplied if the air is cooled properly. The aftercooler is mounted to cool the intake air after it leaves the discharge side of the turbocharger and before it enters the diesel engine.

Fig. 4-7 Air-to-Air Aftercooler

Water Aftercoolers:

Some diesel engine manufacturers still use a water-type inlet air aftercooler. These employ engine coolant routed through the water jacket to reduce the temperature of the pressurized air flowing through it from the turbocharger. A water-cooled aftercooler is capable of lowering the full-load engine turbocharger boost air from a temperature of about 149°C (300°F) down to approximately 93°C (200°F). The ALCC system is capable of lowering the turbo boost air temperature down to approximately 74°C (165°F). The AAAC air-to-air system increases the engine fuel economy by approximately 4% over the water after cooled system.

Fig. 4-8 Water Aftercooler

Intake System Recommendations

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 failsafe protection.
- Inspect intake filter system and verify that it is sized correctly to meet engine requirements. Refer to filter manufacturer's recommendations.
- 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.
- The mechanics should service intake systems 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.

<u>Servicing The Intake System</u>

Assemble a testing system as shown in Figure 4-9.
The components of the system are:

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

Fig. 4-9 An Intake Testing System

The filter elements are easily sealed with duct tape 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 into the intake system. The filter service indicator is usually a good, easily accessible point for the tee. The spray bottle used to test the integrity of the intake system should hold approximately 1 liter of soapy solution in order to service an entire intake system.

Fig. 4-10 A Mechanic Testing the 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. Spray the solution on all hoses, clamps, connections, flanges, manifolds, and coolers for the intake system. Leaks will appear as bubbles on contact with an air leak in any of the intake plumbing.

All defects should be repaired immediately and re-tested. This is not a repair that can be scheduled for a later time.

Job Aid Check List for Intake System:

In the Guidelines and Best Practices the intake system is assigned the highest priority of the six engine systems.

Checkpoints:

- Check operation of filter indicator and measure restriction.
- Measure turbo boost pressure with gauge - 8 psi. (If Applicable)
- Measure turbo boost on DDDL system. (If Applicable)
- Pressure test intake system for leaks.

Actions:

- Replace damaged connector hose and seal intake connections.
- Replace air-to-air cooler if required.
- Replace secondary air filter if required.

NOTE: Use a copy of the Job Aid Checklist at the end of this manual to record measurements and procedures.

2. Exhaust System:

Introduction:

Fig. 5-1 A Typical Diesel Exhaust System

The exhaust system used on modern diesel engines must be laid out in such a manner that the maximum permissible exhaust backpressure never exceeds the manufacturer's recommendations. To test the backpressure in a typical diesel engine exhaust system, a slack-tube manometer can be used or a special low pressure gauge. This is a low pressure gauge designed especially for measuring intake and exhaust backpressure and restrictions on diesel engines.

The use of after treatment devices such as catalytic converters, flame arrestors, water scrubbers, and particulate traps tend to increase the engine exhaust backpressure. Excessive exhaust backpressure has a similar effect on engine performance and emissions as an increased intake restriction. Power output reduction, increased exhaust temperature, CO (Carbon Monoxide), black smoke and particulate emissions all go up.

After treatment devices used on diesel engines can vary tremendously in size and design. The purpose, however, is the same. They allow the escaping exhaust gases, which are under pressure, to expand within the after treatment device, thereby reducing the noise emitted as they exit into the atmosphere.

Fig. 5-2 A Typical After Treatment Device

In addition, some after treatment devices act as a secondary burner for any unburned hydrocarbons left over from the combustion process. Typical noise levels from heavy-duty diesel engines is usually within the 80 to 86 decibels before after treatment devices are installed

Improper maintenance could lead to plugging up or badly restricted exhaust system. The resulting flow restriction will excess the backpressure limits set by the manufacturer.

An excessive exhaust backpressure has a similar effect on diesel engine performance and emissions, similar to increased intake restriction.

Exhaust System Recommendations:

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

- Monitor exhaust backpressure at regular scheduled service intervals using one or a combination of mechanical gauges, or the UGAS analysis system. Backpressure is a prime indicator of how both the engine and exhaust systems are performing with respect to baseline values.

- Inspect the installation of exhaust after treatment systems. Verify that they are properly sized (not 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 after treatment devices. This can be done by measuring backpressure 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 after treatment 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 indicated by a smooth worn down blades on the compressor wheel . 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.

Exhaust After Treatment System Maintenance

Diesel Oxidation Catalysts (DOCs)

These devices are designed to convert carbon monoxide (CO) to carbon dioxide (CO_2). 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:

- Perform emissions measurements on a regular basis to calculate CO (Carbon Monoxide) conversion efficiency. Refer to section 2 page 21 for procedure on emission testing. Efficiency should be between 65% and 95%.

- 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 inches of water 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 build-up. After soaking, re-steam and blow out with compressed air.

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

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 of either a high exhaust temperature condition or a high backpressure condition. If available, smoke density or opacity measurement systems are useful in determining a pass or fail condition of a particulate filter as well. (For a detailed explanation of this procedure refer to Section 2 page 23.)

- 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 in a controlled enviroment and have proper environmental controls for safely ventilating and avoiding exposure to harmful compounds.

Job Aid Checklist for Exhaust System:

Before any maintenance activities are undertaken a set of emissions tests should be performed, taken upstream and downstream of the purifier. This provides a set of values from which to compare the impact of the maintenance activities throughout the day. In addition to the emissions the exhaust backpressure is also measured with a standard mechanical gauge.

Checkpoints:

- Emissions tests before and after exhaust purifier.
- Check exhaust backpressure.
- Visual inspection of complete system for leaks, cracks, etc.
- Check operation and setting of Jake Brakes (If Applicable)

Fig. 5-3 Performing an Emissions Test

NOTE: Use a copy of the Job Aid Checklist at the end of this manual to record measurements and procedures.

Introduction to Tools Used for Exhaust System Analysis:

There are a variety of exhaust gas analyzers on the market that will perform this job. In most cases these tools require proper training to get consistent results. The gas analyzer described below is only one of many that could be used for this purpose.

ECOM AC+ Gas Analyzer:

The ECOM AC+ electronic gas analyzer measures oxygen, carbon monoxide, nitrogen oxide, nitrogen dioxide, gas temperature, and gas pressure. All gas sensors are electro-chemical with a thermocouple and RTD sensor for temperatures, and a piezo resistive sensor for measuring changes in pressure accurately. In addition to measuring the gases mentioned, the analyzer also estimates carbon dioxide output, total oxides of nitrogen and combustion efficiency.

Fig. 6-1 The ECOM AC+ Gas Analyser

The instrument can incorporate up to six gas sensors;
however, sulfur dioxide and hydrocarbons sensors are not being used in the UGAS system. A probe and 15 feet of non-heated sampling line connect the analyzer to the exhaust system. Each exhaust system is fitted with 1/4" NPT (National Pipe Thread) fittings for measuring undiluted exhaust through the probe.

The instrument is capable of operation as a stand-alone device, which can measure gases and print out results. Operations can be performed using the membrane keypad and LCD display and can be saved into analyzer memory and printed out. Each sample erases the previous sample from memory. As a stand-alone device the instrument lacks the flexibility to take time weighted average samples and store historical data in memory. To overcome this the RS232 serial communication port on the analyzer was utilized. This port communicates all data in real time as it is acquired from the sensors. Communicating this real time data to a software interface permits the flexibility required to store time weighted average samples to an integrated database.

Parameter Description

Measured Parameters	Range	Accuracy	Resolution
Oxygen (O2)	0 - 21%	2% of reading	0.1%
Carbon Monoxide (CO)	0 - 4000 ppm	4% of reading	1 ppm
Nitric Oxide (NO)	0 - 4000 ppm	4% of reading	1 ppm
Nitrogen Dioxide	0 - 500 ppm	4% of reading	1 ppm
Sulfur Dioxide (SO2)	0 - 5000 ppm	4% of reading	1 ppm
Combustibles (CxHy - Hydrocarbons)	0 - 6 %	4% of reading	0.01%
Ambient Temperature	0 - 250° F	3 degrees	1° F
Stack Temperature	0 - 1600° F	3 degrees	1° F
Stack Draft	0 - 40.0" H2O	2% of reading	0.01" H2O

Calculated Parameters	Range	Resolution
Combustion Efficiency	0 - 100%	1.0%
Carbon Dioxide (CO2)	0 - 40%	0.1%
Lambda (λ)	0 - 50%	0.01%
Losses	0 - 100%	1.0%
O2 Correction	0 - 10,000 ppm	1 ppm

Fig. 6-2

UGAS Software Application:

The second module of the system is a custom designed Windows software application that communicates directly with the analyzer displaying in real time all measured and calculated values. The interface was designed to be as intuitive as possible for the intended end users - underground mobile mechanics. The gauge controls in the software as shown in figure 3 permit the user to configure warning and alarm display levels for each parameter. The gauge control display window has the flexibility to configure any combination of parameters up to a maximum of eight on each of the two windows.

Fig. 6-3 UGAS Software

The remaining three main display windows are for graphic chart analysis, custom function editing, and databases. The chart analysis window has a list of query filters to select from in querying historical databases. Filters include vehicle number, vehicle type, location, dates and other related fields. The results of each query are displayed in an adjacent graphic analysis screen with flexibility to arrange the data in several different formats.

Testing Protocol:

The third and most critical component is the test protocol. The following protocol for performing an undiluted exhaust test on underground diesel engines was developed in collaboration with CANMET. The protocol accounts for all factors from pre-test conditions through engine loading factors to time weighted average sampling. Pamphlets and on-line multimedia tutorials are provided to assist the mechanics and make the testing as easy as possible. The test protocol is designed to ensure, to the greatest degree possible, accurate and consistent testing of diesel exhaust emissions on underground mobile equipment.

Pre-Test Conditions:

Before taking tests the mechanic must ensure three basic conditions before proceeding:

Fig. 6-4 Insertion of Analyser Probe

- That the engine is at full operating temperature.
- That the vehicle exhaust is equipped with 1/4" NPT (National Pipe Thread) fittings on each side of the exhaust purifier(s). These fittings allow for the insertion of the analyzer probe to acquire undiluted exhaust samples.
- That an instrument such as a hand-held photoelectric tachometer is available for measuring engine rpm during tests.

Emissions Testing Protocol:

- Start the analyzer and log on to UGAS software 3-minute calibration
- Perform a steady state engine stall against the converter and hydraulics system. Brakes on, wheels chocked, unit in second gear, maximum throttle, along with hydraulic stall. Maximum stall time 60 seconds. Perform Baccarat Smoke Test 60 Seconds Read RPM.
- Enter Bacharach Smoke Value - RPM - Test ID Proceed to Gas Sampling .
- Perform a steady state engine stall against the converter and hydraulics system. Brakes on, wheels chocked, unit in second gear, maximum throttle, along with hydraulic stall. Maximum stall time 60 seconds. Start gas sampling within 60 seconds.
- Print and save the results and repeat the test on the opposite exhaust bank on "V" engines.

Note:

Exceeding a 60-second stall condition can potentially cause damage to transmission and hydraulic systems. Use of caution and careful monitoring of all temperatures is advised!

Basic Emission Equipment Operation:

Undiluted Diesel Particulate Measurement:

In addition to diesel exhaust gases, which are easily measured, the particulates in diesel exhaust should also be measured. Unfortunately, accurate portable instruments for measuring diesel particulate in exhaust are not commercially available. Some technicians use opacity meters, but these are quite crude instruments.

CANMET has developed a simple portable system for sampling undiluted particulate matter from production vehicles. The system includes a sampling probe, heated lines, a filter cassette, a constant flow pump and a temperature sensor.

The stainless steel sampling probe is inserted in the exhaust pipe while the engine is running. The pump draws in exhaust air which flows through a 15-foot heated line and through the filter to capture the diesel particulates. The heat is provided by using power from the vehicle battery, and prevents condensation in the sampling line. A high volume pump is calibrated to draw 12 litres per minute. The temperature sensor is a thermocouple from the ECOM analyzer, which records the temperature of the exhaust gas. The temperature of the air is also recorded.

Fig. 7-1 Sampling Undiluted Particulate Matter

The sampling is done over a 60-second steady state stall condition. Perform a steady state engine stall against the converter and hydraulics system. Brakes on, wheels chocked, unit in second gear, maximum throttle, along with hydraulic stall. Maximum stall time 60 seconds. Both gas and particulate samples can be taken simultaneously.

The diesel particulate is collected on a pre-weighed filter. After the sample collection, the filter is weighed again to get the total weight of the sample collected. The volume of exhaust gas passed through the filter is calculated by multiplying the pump flow rate and the sampling duration. The DPM concentration is obtained by dividing the weight of the particulate mass collected by the volume of exhaust gas passed through the filter.

Fig. 7-2 Weighing Sample Collection

Measurement Interpretation:

Note: The following is an excerpt from the actual testing performed during the development of the guidelines. It is not intended that the mechanics would be able to perform these evaluations. It is only included to give the mechanic an overview of the process.

Analysis of Particulate Samples:

Measurement and analysis of the particulate sample filters was done at the NRCan CANMET laboratories in Sudbury and Bells Corners, Ontario. Weight analysis for total mass was done at the Bells Corners facility and the analysis by NIOSH 5040 Thermal Optical method [4] was performed at the Sudbury laboratory.

Weight Analysis:

- Sample filters (silver membrane) were conditioned in an environment chamber for at least one hour at 45% RH ∂ 8%, 22^{o}C ∂ 3^{o}C.
- A Mettler 183 balance, accuracy 1g ∂ 0.00001 g was calibrated using internal calibration procedures.
- A blank filter pair was weighed for determining filter weight changes due to variations in conditions within the weighing chamber between initial and final sample weight determinations.
- Sample filters were weighed and placed in plastic sample holders, which were then capped.
- Upon the sample filter's return, filters were removed from plastic sample holders, placed in petrie dishes, covered and conditioned in an environment chamber for at least one hour at 45% RH ∂ 8%, 22^{o}C ∂ 3^{o}C.
- The Mettler 183 balance was calibrated using internal calibration procedures.
- The blank filter pair was weighed.
- Sample filters were then weighed.
- DPM mass was determined by subtracting initial from the final sample weights, correcting each DPM for changes in blank filter weights. During the field-testing three batches of sample cassettes were assembled with blanks and shipped to the mine. The numbered cassettes were stored in a locker in the underground shop and brought to the office on surface after sample capture.
- Cassettes including blanks were sent to the CANMET laboratory in Bells Corners for analysis.

Thermal Optical Method:

In brief, NIOSH method 5040, speciation of organic and elemental carbon is accomplished through temperature and atmosphere control, and by an optical feature that corrects for pyrolitically generated "EC" (or char) formed during the analysis of some materials (e.g., cigarette and wood smoke). A light from a pulsed diode laser is passed through the filter to allow continuous monitoring of filter transmittance. The analysis process is done in two stages.

In the first stage, organic carbon and carbonate carbon (if present) are volatized from the sample in a pure helium atmosphere. The temperature is stepped to a maximum (about 860^{o}C). Evolved carbon is catalytically oxidized to CO_2 in a bed of granular MnO_2, reduced to CH_4 in a Ni/firebrick methanator, and quantified as CH_4 by a flame ionization detector (FID).

During the second stage of the analysis, a pyrolysis correction (if needed) and EC measurement are made. The oven temperature is reduced, an oxygen (2%)-helium mix is introduced, and the oven temperature is again raised. As oxygen enters the oven, pyrolitically generated EC is oxidized and a concurrent increase in filter transmittance occurs. Correction for the char contribution to EC is accomplished by identifying the time at which the filter transmittance reaches its initial value. This point is defined as the "split" between organic and elemental carbon. Carbon evolved prior to the split is considered "organic" (including carbonate), and carbon after the split and prior to the peak used for instrument calibration (final peak) is considered "elemental."

The 5040 method was used to analyze the first set of samples that were taken on quartz fiber filters. This was done due to inconsistencies measuring total weight due to high humidity combined with quartz fiber filters. There were 21 samples in the first set analyzed with 5040 and quartz fiber filters. For correlation purposes and verification of accuracy, three samples with silver membrane filters were measured with 5040 and correlated to previous samples on the same vehicles with quartz fiber.

Job Aid Check List for Exhaust System Analysis Tools:

ECOM AC+ Gas Analyzer

The electro-chemical gas sensors used in the ECOM unit are recommended for calibration every six months. The analyzer for the project was purchased new from ECOM America and was delivered with all sensors calibrated. The calibration gases used are:

- Carbon Monoxide - 1000 ppm
- Nitrogen Oxide - 100 ppm
- Nitrogen Dioxide - 100 ppm
- Oxygen - Verified against O_2 concentration in NO or NO_2 cal gas

The ECOM analyzer incorporates a three-minute calibration each time the unit is started. All gas sensors are "zeroed" against the ambient air drawn through the probe for the three-minute period. For this reason it is critical that each time the analyzer is turned on the probe remains in as fresh an ambient environment as possible and nowhere near any running exhaust gases.

Particulate Sampling - Gilian Pump:

The undiluted particulate sampling system incorporated a Gillan high volume 30 LPM pump for drawing the exhaust through the 37 mm cassettes. Under ideal conditions this instrument would be calibrated for each sampling session. Calibration of this instrument might be beyond the scope of the mechanics expected work and therefore it may be necessary to have it performed by the ventilation department.

Fig. 7-3 Gilian Pump

Intake Testing:

The intake system can easily be considered the most critical with respect to maintenance and emissions. Ironically the intake system has the least known tools for servicing. In the past ether spray was used for detecting intake leaks by listening for engine acceleration where ether would leak by into the intake and combustion chamber.

Problems with ether including extreme flammability and potential catastrophic engine failure when improperly used have led to the discontinuation of its use. This situation left a huge gap where the only activity associated with intake systems was the regular replacement of air filter elements and blind faith that this practice alone was sufficient.

Fig. 7-4 Intake Testing System

Fig. 7-5 Mechanic Testing an Intake System

A system for methodically testing intake systems with no risks to either the person doing the test or the engine can be prepared by any mechanic. The system is simply a used intake filter element sealed externally with duct tape, an air pressure regulator and hose assembly, and a spray bottle containing a mixture of soap and water. During service the plugged filter element(s) is installed in the intake housing and the air pressure regulator is connected to a fitting on the intake. Compressed air is regulated inside the intake system to no more than 5 psi for safety reasons. Even with the leakage across valves and turbocharger, enough static pressure remains in the system to produce bubbles when the soap and water solution is sprayed on all hoses and connections.

Intake Restriction and Exhaust Backpressure:

A Magnehelic Gauge from Dwyer Instruments can be purchased with a range from 0 - 80 inches of water. The gauge is capable of differential pressure measurements and therefore has two fittings, one for pressure and the other for vacuum measurement. This makes it ideally suited for measuring intake vacuum restriction which is normally in the range of 10 inches of water, as well as exhaust backpressure, typically around 20 inches of water. The gauge is marked on the back to show which side is used for vacuum measurement and which side is used for exhaust pressure measurement. In addition to the portable gauge for servicing, a replacement program should be initiated for the intake tell-tale service gauges that are currently in use. The original small plastic plunger units were found to be anywhere between ineffective to defective.

Fig. 7-6 A Magnehelic Gauge

Fig. 7-7 A Magnetic Tell-Tale Service Gauge

Most of the gauges are installed in locations that were not visible from the operator's compartment so that on the rare occasions that they were actually checked, they weren't being checked properly. A replacement indicator gauge will alleviate this. The gauge can be purchased from Donaldson who manufactures the intake housing and filter systems. The gauge is a standard three-inch mechanical bourdon tube with an appropriate range and scale for the intake system. The plunger indicators should be replaced by the gauges and installed in appropriate locations within sight of the operator's compartment.

NOTE: Use a copy of the Job Aid Checklist at the end of this manual to record measurements and procedures.

3. Fuel Injection System:

Introduction:

The diesel fuel injection system is the heart of the diesel engine and is very important for controlling diesel emissions. Fuel injection system components such as the injection pump and injectors are precision elements, which must be handled with extreme care. They require minimum maintenance and will deliver very long reliable service provided.

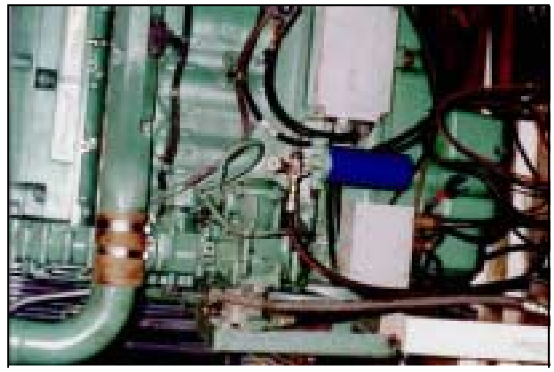

Fig. 8-1 A Typical Fuel System

The following is a list of things that need to be taken into consideration when performing maintenance on fuel injection systems.

- Injection system components are not tampered with.
- System maintenance is performed according to diesel engine manufacturer's recommendations.
- Only high quality fuels are used.

Failure to follow these guidelines will lead to injection system components failure, which will affect engine performance and emission quality.

Failure of Injection System Components can be Grouped into Several Categories:

Injection Pump or Injector Failure:

This problem is usually associated with fuel contamination and is the most expensive to correct. This type of failure will normally result in noticeable performance loss. The engine will be hard to start, will lack power, and have poor acceleration. The engine will suffer from excessive fuel consumption and increased emissions, especially CO (Carbon Monoxide), HC (Hydrocarbons) and smoke. A decrease in NOx emissions will also be evident. The most noticeable effect will be a rapid increase in black smoke and CO emissions. Operation under such faulty conditions could lead to engine overheating, and eventually total engine failure.

Fig. 8-2 Cut-Away of a Contaminated Fuel Filter

Inadequate Fuel Supply:

This condition could be caused by a low fuel level in the tank, plugged-up filters or fuel lines, or internally damaged fuel lines. This problem is the simplest to recognize and easy to correct. Since the engine will fail to start, will misfire and/or will not deliver full power. The situation can be identified early enough and will have only temporary effects on engine life or exhaust emission quality.

Fig. 8-3 Fuel Tank and Fuel Lines

Incorrect Injection Pump or Injector Timing:

Fuel injection timing has a direct bearing on the performance and emissions quality of a diesel engine. If the diesel engine has static injection timing, which is set by the position of the injection pump or the injector height in the case of mechanical unit injectors, the manufacturer optimizes the injection timing during the engine development work. The timing represents a trade-off between fuel economy and the exhaust emission. Diesel engines with static timing are mechanically adjusted during engine assembly or engine repair. The timing generally doesn't change during the service life of the diesel engine.

Fig. 8-4 Typical Fuel System

Advanced Timing:

This condition will normally result in increased NOx emissions. This is usually accompanied by a reduction in CO, HC and smoke. It will also result in lower exhaust temperatures. Excessive advancement of the injection timing will cause hard starting and engine damage.

Retarded Timing:

This condition will normally result in increased NOx emissions. This is usually accompanied by a reduction in CO, HC and smoke. It will also result in lower exhaust temperatures. Excessive advancement of the injection timing will cause hard starting and engine damage.

Fig. 8-5 Mechanic Timing a Diesel Engine

Fuel System Types:

Although new diesel engines employ electronic fuel injection and governing systems to reduce exhaust emissions, there are still many diesel engines in operation equipped with mechanical fuel systems.

This section will introduce you to the main types of fuel systems, both mechanically and electronically controlled. Basic fuel injection system types can be categorized as follows:

- **Individual unit jerk pumps**
- **Inline Pump Systems**
- **Distributor pump systems**
- **Cummins PT (pressure-time) fuel systems**
- **Unit injector fuel systems**

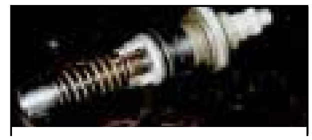

Fig. 8-6 Individual Unit Jerk Pump

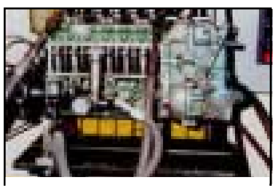

Fig. 8-7 Inline Pump System

Fig. 8-8 Distributor Pump

Fig. 8-9 Cummins PT Fuel System

Fig. 8-10 Unit Injector Fuel

Electronically controlled fuel systems can be applied to all of the mechanical systems listed above.

Individual Unit Jerk Pumps:

The illustration shows the concepts of this type of system where fuel at low pressure from a transfer pump is delivered to the individual pumping units. A supply pump is not required; a gravity-feed system can be used. Within the individual pump housings, a pumping plunger is forced upward by the camshaft to raise the trapped fuel to a high enough pressure to be suitable for injection. The illustration shows a single-cylinder Bosch jerk pump. The letter P in PF stands for "pump" and the F for no camshaft within the pump. The pump is engine mounted and the pump camshaft lobe within the engine block lifts a flat adjustable tappet. The designation PFR indicates that a roller rather than a flat tappet is used. Fuel under pressure is sent through a steel line to the injection nozzle located in the cylinder head. When the fuel pressure is high enough to overcome the needle valve spring pressure, the fuel is sprayed from a series of small orifices in the nozzle spray tip into the combustion chamber. This provides high injection pressure providing good atomization of the fuel.

Fig. 8-11 Bosch Individual Jerk Pump

Inline Pump System:

The inline fuel injection pump employs a design where all of the individual pumping plungers are located within a common housing.
The illustration shows the basic layout of the fuel system for a high-speed heavy-duty diesel engine. A small transfer or supply pump delivers low-pressure fuel to the injection pump housing for operation. The injection pump is timed to the engine gear train. In addition, the injection pump functions to pressurize, meter, and atomize the fuel for combustion.

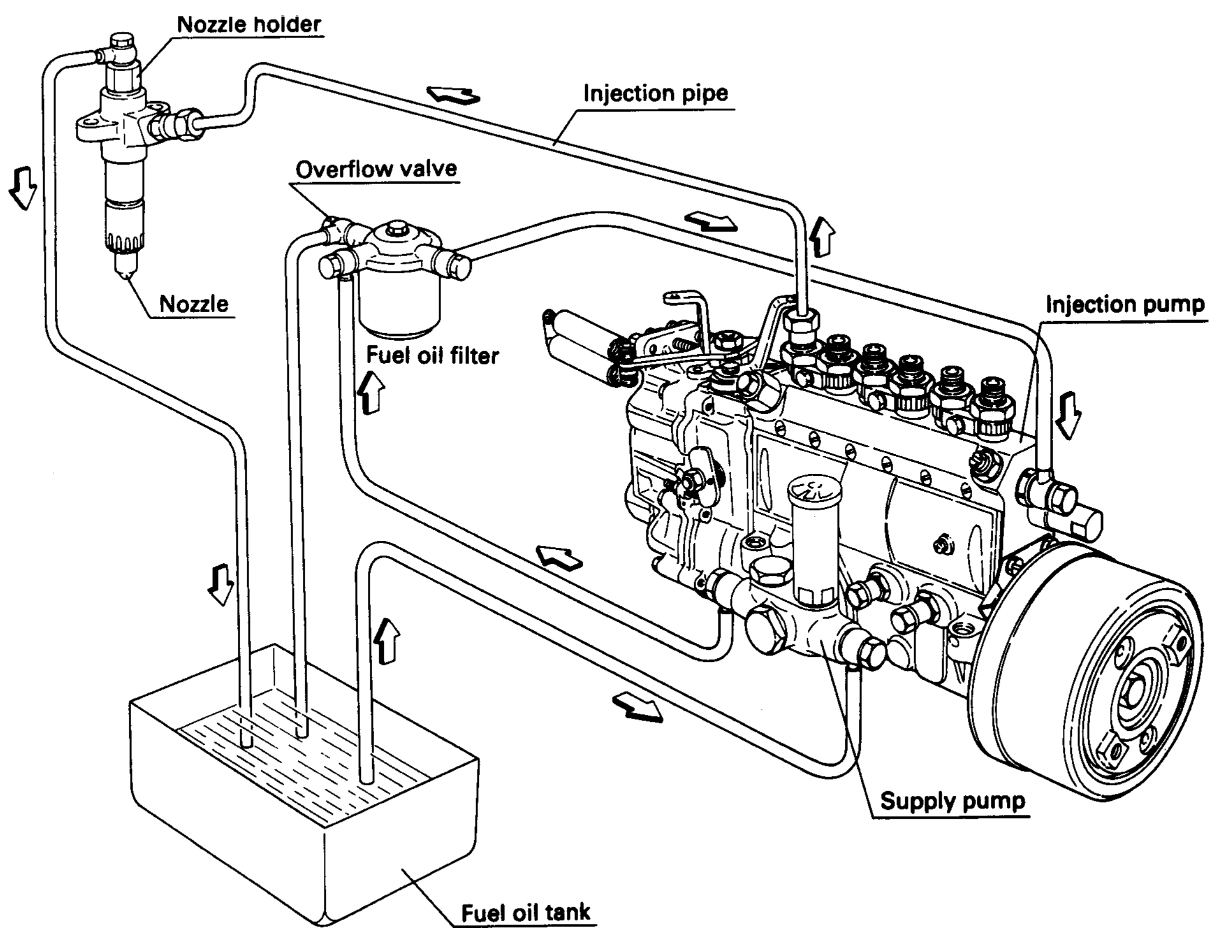

Fig. 8-12 Inline Fuel Circuit

Distributor Pump Systems:

The distributor pump system basic concept is shown in the illustration. The pump is so named because it works something like an ignition distributor in a gasoline engine, in that a spinning internal rotor distributes the fuel. They can deliver, as well as producing lower injection pressures than in a Individual Jerk Pump system. The distributor pump is used extensively on smaller-displacement high-speed automotive and diesel engines.

This figure illustrates a typical distributor pump fuel injection system for a V8 diesel engine. In this system a fuel lift pump delivers fuel at low pressures between 3 and 5 psi (21 to 34 kPa) to a vane pump housed within the end of the injection pump housing. The vane pump produces fuel supply pressures to the pumping chamber between 90 and 130 psi (621 to 896 kPa).

Fig. 8-13 Typical Distributor Pump

This system uses two fuel filters: a primary filter located between the tank and a transfer pump, and a secondary fuel filter located after the transfer pump which removes all impurities from the diesel fuel before it enters the injection pump, or the unit injectors in a low-pressure fuel system or to the injector nozzles on a high-pressure injection system.

Cummins PT Fuel System:

The PT (pressure-time) fuel system is unique to Cummins engines. This system uses a gear-type fuel supply pump along with a governor plunged and operator controlled throttle to distribute fuel to the individual injectors. The speed of the diesel engine determines the pump pressure curve and the available time during which the injector can meter the fuel required for injection.

Fig. 8-14   Cummins PT Fuel System

Unit Injectors:

The unit injector system has been used by Detroit Diesel Corporation (DDC) since the late 1930's when they first released their two-stroke cycle diesel engine models. Basically, a unit injector fuel system combines the pump and nozzle in a single body. The fuel is supplied to each DDC injector at between 50 and 70 psi (345 to 483 kPa) by a gear fuel pump; a common inlet manifold feeds all injectors simultaneously. The unit injector times, atomizes, meters, and pressurizes the fuel for combustion. Fuel is used for cooling and lubrication purposes and flows through a common return manifold which has a restricted fitting at the outlet to maintain system pressure. Excess fuel flows back to the fuel tank.

Fig. 8-15 Unit Injector System

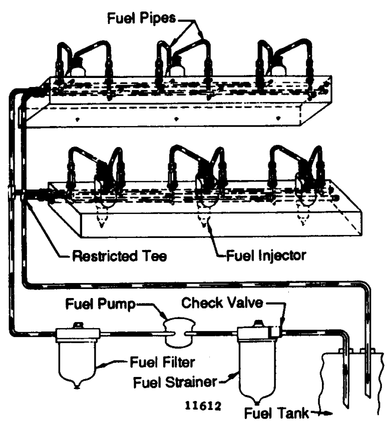

Fig. 8-16 Unit Injector system Circuit

Electronically Controlled Fuel Injection Systems

Electronically controlled unit injector fuel systems are now widely used by many of today's engine manufacturers. Detroit Diesel, Caterpillar, Cummins, Volvo, and Deutz all offer these advanced control systems. The injector pumping plunger is activated mechanically by a rocker arm or by the camshaft directly depending on the manufacturer - all except for the HEUI (hydraulically actuated electronic unit injection) system (pronounced "Hughie"). No rocker arm is necessary in this system as high-pressure oil is used to activate the injector pumping plunger. Both Caterpillar and Navistar International are currently using the HEUI system in a number of their engines.

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Fuel Injection System Recommendations

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 the criteria used for selecting them. 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 (Original Equipment Manufacturers) 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 microns.

- 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.

Job Aid Checklist for Fuel Systems:

The fuel injection system on a diesel engine is equipped with either mechanical unit pump injectors or EUI injector pumps that are actuated off of the camshaft or in the case of Deutz engines, a separate injector for each pumping unit. The unit pumps high-pressure fuel to the combustion chambers or the cylinder head. The only regular service points on this system are to verify RPM settings, pressure test the nozzles if applicable, and setting the intake and exhaust valves at the same time while the valve covers are removed.

Checkpoints:

- Hi and Lo idle RPM settings.
- Fuel pressure and temperature (If Applicable)
- Injector setting and calibration (If Applicable)
- Pressure (pop) test injector nozzles (If Applicable)
- Intake and exhaust valves.
- Fuel filter and water separator.

Fig. 8-17 Mechanic Servicing a Fuel System

NOTE: Use a copy of the Job Aid Checklist at the end of this manual to record measurements and procedures.

4. Cooling System:

Cooling System Recommendations

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 checkpoints 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 would depend on the location of the equipment, but at the very least should be performed at the regular service intervals recommended by the engine manufacturer. This should be incorporated into the operator's education and included in his job description.

- A one-inch water hose and a good commercial degreaser tend 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. Measure the temperature across the inlet and outlet of the rad while performing a stall test. The temperature should show a drop of 10 degrees "F" or more.

- Thermostats should be checked on a regular basis to verify proper operation. Use the infrared heat gun to measure the temperature at which the thermostat opens. Point the gun at the thermostat housing and load the engine. When the thermostat opens you will experience a quick temperature rise.

- 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 scheduled maintenance interval. 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 performed by the Operator:

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

Monthly Maintenance performed by the Mechanic:

- 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 performed by the Mechanic:

- 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.

The 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.

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 an external/internal leak or leaking relief valve. Pressurize the system higher to determine the relief opening pressure for proper setting.

Temperature Probe

A portable infrared temperature probe is used by mechanics specifically for diagnosing cooling systems. This is a simple hand-held instrument that measures surface temperature with a simple point and shoot operation. An LCD display on the instrument updates the value instantly or is capable of logging the value to memory. This is particularly effective in demonstrating and diagnosing cooling systems.

In seconds the efficiency of a radiator could be verified by measuring the differential temperature from top to bottom. Thermostat operation was easily verified by pointing at the thermostat housing and observing the temperature transition as the thermostat opened and closed.

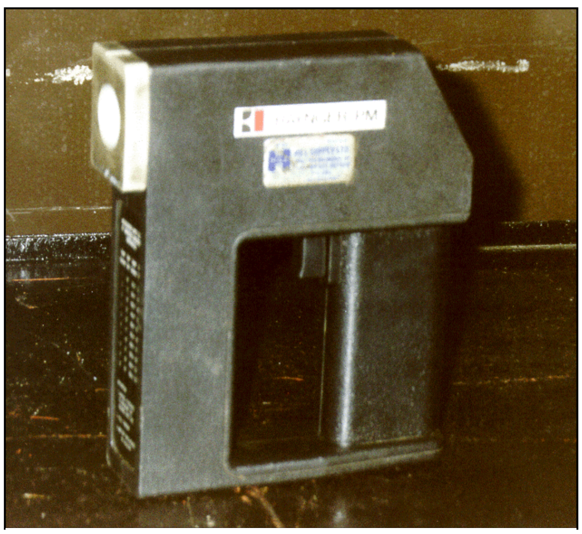

Fig. 9-1 Infra-Red Heat Gun

Job Aid Checklist for Cooling System:

Diesel engines have a cooling system radiator mounted to the side or front of the engine. The cooling system should be checked for the following.

Checkpoints:

- ⊄# Thermostat operation (I.R. temperature gun)
- ⊄# Radiator cleanliness and flow through pressure test
- ⊄# Test strips for additive/inhibitor condition
- ⊄# Fan and belt adjustment and condition

Fig. 9-2 Cooling System (Radiator)

NOTE: Use a copy of the Job Aid Checklist at the end of this manual to record measurements and procedures.

5. Diesel Fuel and Fuel Supply Systems:

Introduction

Diesel fuels are produced by the distillation of crude oil. The diesel fuel produced has certain characteristics that are modified or controlled during production. The quality of a diesel fuel is determined by physical and chemical properties such as, viscosity, flash point, cetane number, and sulfur content. For industrial operations, it is important to select and use high quality diesel fuels.

Even if the best quality fuel is used, it will become contaminated if not handled and stored properly. Contamination with moisture, rain water leaking into drums, condensation forming inside the fuel tanks, dust and dirt (improper storage in dusty areas), use of contaminated fuel transfer pumps, hoses, tanks, or mixing with other fluids such as lubricants must be prevented.

The fuel systems of most diesel engines are equipped with water separators and two-stage fuel filters. Machine manufacturers add these or other fuel filtering systems to their equipment. Such devices will handle small amounts of contamination, but continued or excessive contamination of the fuel system will result in accelerated wear of the engine and the fuel system components.

Fig. 10-1 A Fuel Handling Area

Best Practice Recommendations:

- Use a high quality fuel with high cetane number and low sulfur content.
- Handle the diesel fuel in such a manner that contamination with dust, dirt, moisture and other fluids is prevented.

Sulfur Content:

The sulfur content in diesel fuel affects engine wear and SOx exhaust emissions. Low sulfur fuels (less than 0.05 %) are most desirable from an engine wear and environmental standpoint.

Sulfur is a non-metallic element present in diesel fuel that will cause combustion chamber deposits and wear on pistons, rings, and cylinders. This contributes to elevated particulate emissions. The use of diesel fuel with a sulfur content as low as possible is desirable.

Cetane Number:

The cetane number is a measure of the ignitability of the fuel. The cetane number affects the ignition delay, which has an effect on engine performance, fuel economy, and emissions.

From a diesel engine standpoint, diesel fuels having a cetane number of 50 or greater should be used for best results. Diesel engines that are run on low cetane fuels will suffer from excessive CO, HC, particulate and smoke emissions, especially at low speed/low load/low temperature operation.

Operating a diesel engine with fuel that has a low cetane value will result in a poor combustion process.

Viscosity:

The term "viscosity" refers to the measure of the liquidity of the fuel, which affects its ability to vaporize. Viscosity is measured by observing the time required for a specific volume of fluid to flow under steady state conditions through a short tube with a specific size bore. The flow is measured with a viscometer.

The viscosity of fuel oil is measured at 77^{o}F and at 12^{o}F. Viscosity of diesel fuel affects the pattern of spray in the combustion chamber. A low viscosity fuel produces a finer mist, which is desirable.

Flashpoint:

The term "flashpoint" refers to the temperature of the fuel at which the vapours it produces ignite when a flame is exposed over the surface of the liquid fuel. The flashpoint of diesel fuel is 100^{o}F for 1-D ,and 125^{o} for 2-D fuel.

Most manufacturers recommend the use of 1-D diesel fuel for their diesel engines.

Fuel Quality and Handling Recommendations

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 kept clean and orderly to reduce the possibility of fire and contamination.

- 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 to minimize the chance of the fuel becoming contaminated with water and dirt. 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 serviced regularly to make sure they are kept clean and dirt-free.

- 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 fuel tanks should be equipped with a quick connect fill system to prevent dirt from entering the system, or should be equipped with strainers.

7. Lubrication:

Lubrication Recommendations

Engine lubrication requires more attention to handling than most people give it. It is not merely a matter of topping up oil levels or replacing oil and filters. Mechanics and operators both need to recognize lubrication as an important factor in engine maintenance. Maintaining a proper oil level in the crankcase is essential to minimizing emissions. The practice of overfilling a crankcase at the start of a shift to compensate for leaks or oil consumption creates more problems than it solves, especially with respect to emissions. While low level problems will obviously cause wear and eventual failure problems, overfilled oil will cause problems with excessive emissions.

- As with the fuel filters, price should not determine which engine oil filters are purchased. 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, from the bulk storage system right through to 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 from the oil is being used effectively by 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. Operators should be checking the oil at the beginning of their shift. Mechanics should ensure that the right dipstick is in use on each piece of equipment on their beat.

- Oil and fuel filters should NOT be pre-filled on a workbench before installation due to the possibility of unnecessary contamination.

Lubrication Classification:

Engine lube oils and their classifications are often disregarded or misunderstood. For mining diesels, only the oil meeting the engine manufacturer's 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

- 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

- CA Light to moderate duty, high quality fuels MIL-L-2104A; 1954
- CB Light to moderate duty, lower quality fuels 1955 - 1963; high sulfur 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.

Lubrication System Checks:

Maintaining a proper oil level in the crankcase is essential to minimizing emissions. The practice of overfilling a crankcase at the start of a shift to compensate for leaks or oil consumption creates more problems than it solves, especially with respect to emissions. While low level problems will obviously cause wear and eventual failure problems, overfilled oil will cause problems with excessive emissions.

This issue is more of an educational practice that mechanics are encouraged to follow up on with operators.

Some Engine Manufacturers recommend only the use of premium multi grade oil (15-40).

Fig. 11-1 Mechanic Checking Oil Level

Conclusion:

This manual provides the steps required to implement a condition-based approach to diesel engines maintenance rather than the traditional time-based maintenance practiced by many industries today. A condition-based approach to servicing, repairing, and maintaining diesel-powered equipment is cost effective and improves diesel emissions. Traditional engine maintenance based on a timeline or preventative maintenance programs that change diesel engine components is not cost effective and fails to properly reduce diesel emissions. An equipment condition approach to maintenance will not only reduce operating costs, but will extend operating time on the equipment. Maintenance will only need to be done when there is evidence of a deteriorating engine condition indicated by a steady increase in the monitored engine emissions.

The research study used as a basis for the preparation of this manual showed, for example, that changing injectors based solely on a timeline program did not make a measurable difference in the emissions on a DDEC series 60 engine. Had emissions been documented on a regular basis, as suggested in this manual, it would have been apparent that the injectors did not need replacement. The parts cost of replacing a set of injectors on a DDCE six-cylinder 60 series is very expensive. Adding to this, labour and down time costs for unnecessary repairs will easily justify the implementation of the maintenance approach as described in this manual.

Diesel Emissions - Job Aid Check List

Employee Name: ____

Date: ____

Equipment Type: ____

All Tests To Be Done At Operating Temperature

Intake System Checks	Left Bank	Right Bank
Filter Indicator Operation		
Measure Restriction		
Pressure Test Intake System		

Exhaust System Checks	Left Bank	Right Bank
Check Backpressure Before Purifier		
Inspect for Leaks		
Check Jake Brake Operation		

Engine System Checks	OK	Needs Adj
High RPM		
Low Idle		
Fuel Pressure Low Idle		
Fuel Pressure High Idle		
Intake & Exhaust Valve Adjustment		
Fuel Filters		
Drain Water Separator		
Fuel Temperature		

Cooling System	OK	Needs Adj
Coolant Level		
Radiator Clean (External)		
Belt Tension		
Coolant Condition		

Rad Cap Condition