GUIDELINE

Management of diesel emissions in Western Australian mining operations

MIAC

Government of **Western Australia**
Department of **Mines and Petroleum**
Resources Safety

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Guidelines

A guideline is an explanatory document that provides more information on the requirements of legislation, details good practice, and may explain means of compliance with standards prescribed in the legislation. The government, unions or employer groups may issue guidance material.

Compliance with guidelines is not mandatory but they could have legal standing if it were demonstrated that the guideline is the industry norm.

Who should use this guideline?

This guideline should be used by anyone planning or conducting underground mining where diesel engines are likely or are being used, particularly those persons responsible for the occupational health of personnel.

Foreword

This guideline is issued by Resources Safety under the *Mines Safety and Inspection Act 1994*, and has been endorsed by the Mining Industry Advisory Committee (MIAC).

The Act

The *Mines Safety and Inspection Act 1994* (the Act) sets objectives to promote and improve occupational safety and health standards within the minerals industry.

The Act sets out broad duties, and is supported by regulations together with codes of practice and guidelines.

Regulations

The Mines Safety and Inspection Regulations 1995 (the regulations) provide more specific requirements for a range of activities. Like the Act, the regulations are enforceable and breaches may result in prosecution, fines, or directions to cease operations and undertake remedial action.

Application

The provisions of this guideline apply to all mines as defined in section 4(1) of the Act.

1 Introduction

1.1 Background information

The use of diesel-powered plant in underground mining has steadily increased since the 1960s. During this time, diesel-driven mechanised machinery has replaced physical labour or pneumatically driven machines. Today there is a mechanised diesel unit for many underground operation.

As a result of the combustion process, diesel engines emit diesel particulate matter (DPM), exhaust gases, including a wide range of organic vapours, and a small amount of metallic compounds. For the purposes of this guideline, these components are collectively referred to as diesel emissions.

Diesel emissions pose both short- and long-term risks to health, ranging from mild effects, such as headaches, irritation and nausea, to respiratory disease and cancer. There is also the issue of chemical asphyxiation from carbon monoxide.

Appendix 1 lists the legislative provisions that apply to the ventilation of underground mines in Western Australia and monitoring of airborne contaminants.

In line with sound risk management practices, the risks from diesel emissions should be assessed and controlled to an acceptable standard. There is currently no national exposure standard for DPM. However, a number of regulatory agencies in Australia have adopted the Australian Institute of Occupational Hygienists (AIOH) exposure limit recommendation of 0.1 mg/m^3 as elemental carbon measured as a time-weighted average over eight hours (adjusted for extended workshifts). The AIOH recommendation was developed because of the irritant health effects from exposure to diesel emissions, with the view that compliance would reduce the risk of health effects.

While there are no national regulations or standards in place that limit emissions from non-road diesel engines, Australia has benefited from the importation of engines compliant with United States (EPA Tier 1 to 4), European Union (Stage I to IV) and other emission standards, which has contributed to reduced emissions. Industry data submitted to Resources

Safety over the past few years indicate that it is reasonably practicable for underground mines to achieve compliance with the AIOH recommendation of 0.1 mg/m^3 for DPM. However, some sites have not effectively controlled emissions to maintain employee DPM exposure levels below 0.1 mg/m^3.

Industry experience indicates that successful diesel emissions management programs are those taking a holistic approach to deal with a broad range of risk factors. The best outcomes are achieved by addressing this hazard at the mine design stage and consulting the ventilation officer when planning mining operations. Successful strategies are those that eliminate or reduce:

- diesel engine emissions at their source
- the transmission of DPM through the underground environment
- personal exposure.

1.2 Scope

Diesel emissions are a particular problem in enclosed environments such as underground mines, workshops and train load-out tunnels where exhaust particulates and gases can accumulate if ventilation is inadequate.

This guideline describes the nature and production of diesel emissions, the associated risks, and recommends ways to mitigate exposure. Chapters 6 to 8 introduce potential strategies to address issues associated with emission, transmission and exposure. While there are proven control strategies that can be implemented, such as diesel engine maintenance procedures, all measures should be considered to ensure diesel emission exposures are maintained as low as reasonably practicable.

It is imperative that implemented measures are maintained and monitored by mine management.

Note: This guideline applies to all underground mines except those extracting coal.

1.3 Classification of diesel emissions as a carcinogen

In 2012, the International Agency for Research on Cancer (IARC) classified diesel engine exhaust emissions as carcinogenic to humans (Group 1), based on sufficient evidence that exposure is associated with an increased risk for lung cancer. A positive association, with limited evidence, of an increased risk of bladder cancer was also found.

The IARC was careful to state that the classification of diesel emissions as a carcinogen was independent of determining the duration, frequency and concentration of exposure required to produce an actual risk. As with many exposures, the probability of harm increases with the level of exposure, and this was an important aspect of the IARC's findings. The IARC working group pointed out that the main studies that led to this conclusion were in highly exposed workers.

The IARC classification should not be misinterpreted to mean that Western Australian miners are at elevated risk — the historical DPM concentrations found in the studies were many times greater than the currently accepted limit in this State. However, the inherent risk of developing cancer from exposure to DPM is still present.

1.4 Nanoparticles

The Department of Mines and Petroleum is aware that technological advances, particularly in regard to monitoring nanoparticles in diesel emissions, and emerging epidemiological studies may lead to calls for an exposure standard, and mining operators should consider this when developing their long-term management strategies.

2 Management process

The management of diesel emissions, and occupational exposures to those emissions, requires an integrated strategy incorporating efforts from all key departments on a mine, including management, production, maintenance, supply and occupational health and safety.

A risk-based approach towards managing diesel emissions should comprise the following steps:

- identify possible diesel emission sources
- conduct risk assessment
- undertake occupational exposure sampling to determine health risk
- undertake a complete gap analysis of diesel emission controls
- implement suitable controls for identified gaps
- re-evaluate effectiveness of controls through monitoring and measurement
- monitor, audit and update risk assessment and management plan.

Where there is exposure to diesel emissions, a diesel emissions management plan should be developed and implemented. The aim of the management plan is to provide the identified stakeholders with an understanding of the mine's strategy of managing diesel emissions, and their roles and responsibilities within this process. A diesel emissions management plan should consider:

- roles and responsibilities
- sources of diesel emissions
- health risk assessment
- emission controls
  - equipment design and specification
  - fuel management
  - emission reduction devices
  - maintenance strategies

- transmission controls (ventilation)
  - ventilation design
  - ventilation performance
- exposure controls
  - education and training
  - enclosed cabins
  - personal protective equipment.

Operations should consider establishing a formal diesel emissions management plan committee.

Appendix 2 contains sample checklists for the management of diesel emissions.

3 Formation of DPM and other pollutants

3.1 What are diesel emissions?

Overview

Diesel emissions are a complex mixture of particulate matter and gaseous components.

The particulate component comprises solid carbon cores, produced during the combustion process, with a range of organic carbon compounds condensed onto the solid nucleus, as well as some metallic compounds. More than 90 per cent of the carbon particulates are respirable, having diameters of 1 µm or less, which are capable of entering the deepest regions of the lungs.

The gaseous components include water vapour, oxides of carbon (CO, CO_2), oxides of nitrogen (NO_x), volatile organic compounds, and unreacted gases from air such as nitrogen.

Relationship between elemental carbon and total carbon

Elemental carbon is currently used as a surrogate for measuring DPM levels in underground mines because:

- it can be accurately determined at low concentrations
- diesel engines are the only source of submicron elemental carbon in underground metalliferous mines.

Research has shown a direct correlation between elemental carbon concentrations, DPM mass and total carbon when diesel particulate filters were not used. The use of filters will significantly reduce overall emissions but some filters increase either the gas or finer particle component.

Morphology and structure

The high surface area to volume ratios of the core particles of DPM mean they absorb significant quantities of hydrocarbons originating from the unburnt fuel, lubricating oils and compounds formed during the combustion cycle (Figure 1). More than 1,800 compounds have been identified, including polycyclic aromatic hydrocarbons, condensed liquid hydrocarbons, metals and sulphate compounds.

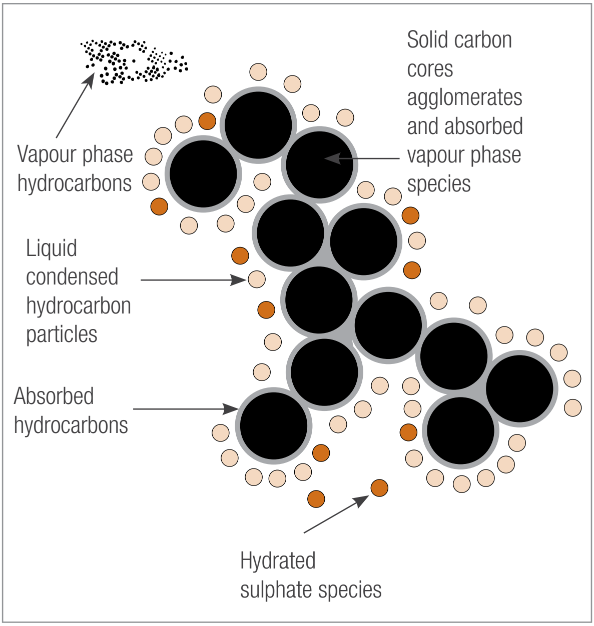

Figure 1 Schematic representation of DPM (after Twigg and Phillips, 2009)

Size and weight distribution of DPM

The size and weight distribution of DPM depends on the fuel, engine, machinery, maintenance, work practices and environment. Typically:

- about 90 per cent of DPM is less than 0.03 μm (30 nm) in diameter, but comprises only 10 per cent of the mass (Kittelson et al., 2002)
- most of the mass of DPM is composed of carbonaceous agglomerates and adsorbed materials, ranging in size from about 0.03 to 0.5 μm (Kittelson et al., 2002)
- the remaining 5 to 20 per cent of the DPM mass consists of particulates larger than 1 μm, which are generally deposited on cylinder and exhaust system surfaces (Kittelson et al., 2002; Watts et al., 2009).

3.2 Formation of diesel emissions

Diesel engines work by igniting a mixture of fuel (a hydrocarbon) and intake air in the combustion chamber. At high temperatures, fuel may decompose rather than burn, leaving a complex residue in the chamber. Most of the residue will combine with oxygen and burn during later stages of the combustion process. However, the remainder will be emitted from the engine exhaust as solid particulate matter, forming the core of a diesel particulate agglomerated with unburnt hydrocarbons.

Incorrect fuel-air ratios may also lead to the formation of organic carbon compounds when hydrocarbons are not fully oxidised during the combustion process.

3.3 Pollutants associated with diesel engine emissions

Unburnt hydrocarbons

Hydrocarbons in the gaseous phase are a complex mixture of many chemicals, such as volatile organic compounds and semi-volatile organic compounds. They also include polycyclic aromatic hydrocarbons.

Gaseous emissions

Carbon monoxide

Carbon monoxide is produced when there is incomplete oxidation of carbon in the fuel, generally from a lack of oxygen or a low temperature in the chamber. Under conditions that might produce local fuel-rich mixtures, such as overloading and over-fuelling, diesel engines may produce higher concentrations of carbon monoxide.

Carbon dioxide

High levels of carbon dioxide may build up if diesel engines are used in confined or poorly ventilated spaces, such as headings.

Oxides of nitrogen

At high temperatures, nitrogen from the intake air will react with oxygen and hydrocarbons to form nitrogen oxide compounds (NO_x), primarily nitric oxide and nitrogen dioxide. In the combustion chamber, these compounds form outside the fuel-rich region of the fuel plume, where the conditions are optimal.

The formation of NO_x increases at higher combustion temperatures and lean conditions, whereas DPM mass formation increases at lower combustion temperatures and richer conditions. Therefore, lowering NO_x emissions through in-cylinder techniques increases DPM.

Sulphur dioxide

Sulphur dioxide forms when sulphur in the fuel and lubrication oil oxidises during the combustion process. This gaseous emission can damage or poison exhaust catalysts in modern diesel engines.

Other irritant gases

Other irritant gases, including aldehydes, may be present in varying levels in raw diesel emissions depending on engine operation, and fuel and lubrication quality. Acrolein is the strongest irritant of the aldehydes produced in diesel emissions.

4 Exposure limits and health effects

4.1 Exposure limits

Concentrations of gases and vapours are usually indicated in parts per million (ppm) by volume. The time-weighted average (TWA) exposure standards for some common gases found underground are 30 ppm for carbon monoxide, 5,000 ppm for carbon dioxide and 3 ppm for nitrogen dioxide.

The airborne concentrations of particulate contaminants are expressed as milligrams of substance per cubic metre of air (mg/m^3). The currently accepted TWA exposure limit for mine workers in Western Australian mines is 0.1 mg/m^3 of elemental carbon. While there is no national standard, the accepted limit for Western Australia is based on AIOH guidance. Research projects show that some Australian mines have exceeded these recommendations.

4.2 Health effects of diesel emissions

The toxicity of diesel emissions depends on a number of factors, including the chemical and physical form, dose and route of exposure. A large number of complex and potentially harmful substances can be adsorbed onto DPM.

Underground workers exposed to diesel emissions may experience a number of adverse health effects, including:

- headaches
- eye and nose irritation
- asthma
- nausea
- lung inflammation
- cardiopulmonary disease
- cardiovascular disease
- cancer.

Excessive exposure to gases can also adversely affect the human body, as described below.

- Carbon monoxide reduces the capacity of blood to carry oxygen, which can result in loss of consciousness and possibly death. There is also a possible link between long-term exposure and the development of heart disease.
- Carbon dioxide can affect sensory perceptions, and cause disturbed judgement, mood changes and, in extreme situations, death.
- Nitrogen dioxide can produce severe respiratory irritation. Severe lung problems such as emphysema and chronic bronchitis can occur immediately or after a delay of several days.

Other emitted gases can irritate sensitive parts of the body, such as the nasal passages, throat, lungs and parts of the eyes.

5 Monitoring diesel emissions

5.1 Personal exposure monitoring

Elemental carbon is considered the best indicator or marker for personal DPM exposure, as it constitutes a significant fraction of DPM.

The US-based National Institute of Occupational Safety and Health (NIOSH) recommends using the associated thermal optical analysis method (i.e. method 5040) to measure elemental carbon as it is accurate and validated. Appendix 3 outlines the method, which is approved by the State Mining Engineer.

5.2 Real-time monitoring

Being able to relate non-conforming results directly to the atmospheric conditions of the mine or mining activity undertaken at the time of sampling can provide valuable information when considering how to reduce exposure. Real-time positional monitoring for DPM can be undertaken using commercially available equipment. However, care should be taken when interpreting the results and they should not be compared to personal exposure standards.

Real-time DPM analysers generally use light scattering or laser absorption by elemental carbon to calculate the concentration in the exhaust, whereas opacity meters measure the amount of light transmitted through the exhaust stream to give an indication of the particulate loading in the exhaust. Since they are not specific to elemental carbon, opacity readings are more useful for comparative purposes such as determining how well an engine has been tuned.

Equipment that incorporates exhaust gas analysis and opacity measurement within a single system is also available. These range from small portable analysers weighing between 6 and 15 kg to workshop-bound systems in excess of 120 kg. The equipment can operate in a range of environmental conditions, including the raw exhaust stream, and is capable of measuring elemental carbon concentrations from 0.001 to 400 mg/m^3. However, there are significant calibration issues with these devices and research is required to confirm the technique as an internationally validated standard.

6 Source controls

6.1 Introduction

Reducing diesel emissions at source should be the primary consideration when applying the hierarchy of control. Strategies typically focus on the fuel, the combustion efficiency of the engine, and reducing or removing harmful emissions.

6.2 Fuel selection

Ultra-low sulphur and other low-emission diesel fuels and low-sulphur lubricants should be used where practicable.

6.3 Engine selection

A major contributor to poor air quality in an underground mine is the exhaust emissions from diesel equipment. Ventilated fresh air is constantly contaminated by diesel emissions and so lowering emissions will help improve air quality. Therefore, the principle objective should be to minimise diesel emissions from each piece of equipment. Mine management should require suppliers to provide equipment that meets specific emission standards.

In the United States, diesel engines are classified according to federal emission standards administered by the Environmental Protection Authority (EPA). There are four categories, with Tier 4 engines meeting the most stringent emission standards. The American non-road emission standards are aligned to a large degree with those of the European Union, which range from Stage I to IV with decreasing emissions.

Although EPA Tier 3 and 4 engines have the lowest emissions, Tier 1 and 2 engines are still used in Australia.

6.4 Engine refurbishment

Tier 1 and 2 engines are less sophisticated than more modern engines and produce low torque compared with typical surface machinery. When these engines are overhauled, there is an opportunity to install new components supplied by the original equipment manufacturer (OEM) to take advantage of low sulphur fuels and improve fuel efficiency. Such components include more advanced fuel injector systems and electronic control unit functionality, which allow the operating life of older engines to be extended with reduced emissions. With the right configurations, refurbished engines and their supporting components can closely emulate the emission characteristics of Tier 3 and 4 engines.

6.5 Maintenance and repairs

Good maintenance practices lead to reductions in raw exhaust emission levels and ultimately lower worker exposures. It is crucial that maintenance plans, focusing on emissions, is integral to the overall plan for reductions in workplace exposures.

Operators should be aware of their equipment's emissions and report any changes, such as visible black smoke, to maintenance.

Servicing should be undertaken by competent personnel who can interpret diesel emission monitoring results to minimise emissions following maintenance and repairs.

If maintenance is inadequate, the performance of any diesel engine will degrade, with a resultant increase in particulate emissions. The effectiveness of the maintenance regime can be measured by:

- conducting DPM baseline tests prior to the diesel engine commencing operation
- regularly monitoring raw exhaust levels of diesel engines over their operational life cycle. For diagnostic purposes, this is best undertaken at the same time as a raw exhaust gas test:
  - for diesel engines that meet or exceed American EPA Tier 2 or European EPA Stage II emission standards,

the results should not deviate from the baseline test by more than 30 per cent
    - for diesel engines that do not meet American EPA Tier 2 or European EPA Stage II emission standards, the results should not deviate from the baseline test by more than 15 per cent
- the cause of any deviation from the baseline should be determined and recorded, and appropriate action taken to return the engine emission levels to their baseline status.

6.6 Emission control devices

Overview

Devices are available that reduce diesel emissions by either removing solid fractions or converting pollutants into less harmful emissions.

DPM filter systems can efficiently trap the solid fraction of diesel emissions although emerging technologies also suggest an ability to remove nanoparticles. Engine design, mine operating parameters and engine duty cycle should be considered as part of the filter selection.

The non-solid fraction of emissions, such as soluble organic compounds, is captured at much lower efficiencies in DPM filters. Diesel oxidation catalysts and ultra-low sulphur fuels can be used to control this non-solid fraction. Scrubbing, acoustic agglomeration and cyclonic processes are other methods to reduce emissions.

Particulate filters

Particulate filters are used to treat diesel exhaust emissions.

In partial flow-through devices, the exhaust gases and particulate matter follow a convoluted, but restricted, path through a mesh or wire network. The mesh can be catalysed or uncatalysed.

In wall-flow filters, which can achieve a filtration efficiency of at least 85 per cent, the exhaust emissions travel through a honeycomb network of channels that are alternately plugged, forcing the gases through the porous side walls. The filter develops a layer of retained particulates, which can be burnt or oxidised to regenerate the filter.

Incomplete regeneration results in soot build up, reducing filtration efficiency. Uncontrolled regeneration can lead to high levels of carbon monoxide.

Catalytic converters

A catalytic converter for diesel engines typically has separate reduction and oxidation catalysts comprising a ceramic structure coated with a precious metal catalyst.

The reduction catalyst is the first stage of the catalytic converter and reduces NO_x emissions to oxygen and nitrogen molecules.

The oxidation catalyst converts carbon monoxide and unburnt hydrocarbons into carbon dioxide and water.

Under certain conditions, some diesel oxidation catalysts can increase nitrogen dioxide levels. In-cylinder controls aimed at decreasing NO_x formation are almost always intended to lower the peak temperatures during the combustion process. In modern diesels, this is largely accomplished through exhaust gas recirculation. Secondary control through various after-treatment technologies, such as lean NO_x catalysts and selective catalyst reduction can also be used to further reduce NO_x emissions to acceptable levels (Bugarski et al., 2011).

While it is difficult to simultaneously reduce NO_x and DPM, it is possible to minimise both using a combination of raw exhaust analysis and an emissions-based maintenance program.

Scrubbers

Scrubber systems are used to remove particulates and gases from industrial exhaust streams.

A wet scrubber cleans engine exhausts through the contact of target compounds and particulate matter with the scrubbing solution, which may be water, a solution containing additives, or an emulsion.

Acoustic agglomeration

The effect of ultrasonic acoustic energy on diesel particulates is to increase their energy level to a point where they are attracted to form larger particulates which results in an increase in their mass and size. These larger and heavier particulates can then be removed using filters. Such technology is not yet comercially available.

Cyclones

Cyclonic separation removes particulates from an air, gas or liquid stream through vortex separation, without the use of filters. The DPM mass can be significantly reduced by combining acoustic agglomeration with micro-cyclones (Glynn, 2011). Such technology is not yet comercially available.

6.7 Testing of exhaust components

Raw exhaust tests should be conducted to accurately measure the effectiveness of exhaust treatments. The testing of components is often performed on site and in the workshop. Where sophisticated dyno equipment is not available, handheld gas and DPM measuring devices can be used. However, they require particular skills for correct calibration and fitting with dilution units.

A trans-stall test is also recommended. This requires the engine to be under load in low gear with a hot engine and hydraulics, and the engine revving at about 70 to 80 per cent capacity for about 30 seconds. High or low idle tests are not adequate.

6.8 Engine operation

Engines should be operated to optimise combustion thereby reducing diesel emissions. For example, this can be achieved by:

- driving to prevailing conditions
- limiting idling
- limiting over-revving.

6.9 Remote vehicle emission monitoring

Vehicle emission control units monitor, capture and can store data about the engine, exhaust stream, and other parts of the vehicle. Rudimentary information can be collected and sorted for preventative maintenance purposes. Much of this information can also be integrated into a remote emissions monitoring system. Pre-determined exceedance alarms can be set for temperature and various diesel emissions. The monitoring systems are typically located in the mine control room.

7 Transmission controls (ventilation)

7.1 Introduction

There have been many studies into diesel engine emissions and personal exposure. However, few have investigated the transmission of diesel emissions between the source and exposed workers.

Most DPM behave very differently from gaseous contaminants when transported within mine airways, although ultrafine particles can behave more like a gas.

The concentration of diesel emissions along the transmission path will depend on the number of diesel engines in the airway. Other factors to be considered include air velocity, size and density of DPM, humidity, dust particles and the presence of mists. Larger particulates fall out of the air stream while smaller particulates will remain suspended for longer periods, and have the potential to lead to worker exposure at distant locations.

Mine ventilation plays an important role in the management of diesel emissions. There are regulatory requirements regarding the air quantity required for underground mines when operating diesel equipment. However, the removal of DPM can involve more complex ventilation design beyond that necessary to meet the legislative requirements for air supply. Adopting good ventilation design standards should be part of the holistic approach to diesel emission management.

When designing mine ventilation systems, also consider the potential presence of other contaminants such as asbestos, radon gas and respirable dust.

7.2 Mine ventilation design

The difficulty with maintaining the DPM level at or below the accepted TWA exposure limit of 0.1 mg/m^3 is that the ventilating air requirements for diesel unit operations relate to the size of the engine and gaseous emissions, rather than particulate emissions.

Ventilation systems in existing underground mines have typically been designed to meet the minimum legislative requirement, however the key to ensuring sufficient air supply to address the DPM issue is to adjust ventilation according to mining activity underground.

Regulating airflow in disused areas is generally not practical unless a ventilation-on-demand (VOD) system is utilised. Most underground mines do not employ VOD systems, resulting in demand for more total air than would be required for the diesel fleet.

Sub-standard ventilation occurs when the air quantity and quality in work areas are below that required to adequately disperse and dilute contaminants present in the work environment. This condition most commonly occurs in secondary ventilated areas, where the air being delivered is not drawn from a fresh source. Exposure to DPMs and other contaminants will increase when diesel equipment is operated in these inadequately ventilated areas.

It is calculated that ventilation air quantities six to eight times greater than those currently found in most mines are required to adequately maintain the level of diesel emissions below the accepted TWA exposure limit. Ventilation system design should take this into consideration and ensure that only the purest air, in sufficient volumes, is supplied to working areas. Air drawn from haulage and travel ways is already contaminated and, therefore, does not effectively dilute the disperse additional contaminants created by activities occuring at the working face. For this reason, only parallel ventilation circuits should be employed.

Dust particles drawn into the air filters of diesel equipment can contribute to a decrease in engine performance and a corresponding increase in diesel emissions. Consequently, ventilation may assist in controlling diesel emissions by maintaining a cleaner environment to aid engine performance.

8 Exposure controls

8.1 Introduction

While emission and transmission controls are the most important factors in managing diesel emission exposure, exposure controls also play an important role. However, due to the higher reliance on behavioural compliance, they require an appropriate level of management commitment to ensure their effectiveness.

Periodic observations and refresher training will ensure employees appreciate the importance of all the control measures in place, and their roles and responsibilities in maintaining such controls.

8.2 Employee education and training

Education and training focussed on diesel emissions management should be developed, implemented and regularly provided to all employees involved in the operation and maintenance of diesel emission sources, such as light and heavy vehicles.

The employee education and awareness program should address:

- composition of diesel emissions
- health effects of diesel emissions
- sources of exposure
- monitoring, measuring and evaluation of exposure
- best practice to mitigate exposure, including
  - driving to prevailing conditions
  - limiting idling
  - limiting over-revving
- selection and use of personal protective equipment (PPE).

Workers directly responsible for managing controls of diesel emissions should undergo specific training relating to the use, care and maintenance of such controls to ensure their effectiveness. For example, service crews should be trained in the maintenance tasks required to reduce emissions.

Operators should understand the benefits of pre-start and shut-down procedures. Operator training should also address factors in the operation of diesel-powered vehicles that can have detrimental effects on engine performance and increase emissions. A diesel engine working at a steady state at peak horsepower is more efficient with reduced emissions. However, the transient operating and duty cycles within an underground mining environment make this difficult to achieve. Consequently, the following should be emphasised:

- engine idling should be kept to an absolute minimum
- throttling or transient operation should be minimised — modulated shift automatic transmissions assist operators to change direction and speed without releasing the throttle
- the engine load directly influences DPM production — systems that apply mechanical load to the engine such as transmission, hydraulics, and brakes should be verified for proper settings at scheduled service intervals.

8.3 Enclosed equipment

Enclosed cabins can be an effective means of reducing employee exposures to diesel emissions, although their use will not be practical for all activities in an underground mine. They should be air-conditioned and positively pressurised to ensure operators are both comfortable and protected from exposure to emissions.

The operator is only protected while in the cabin and if the cabin seals and air conditioner filters are well maintained. This includes checking seals, leak testing and managing filters.

8.4 PPE

Applying the hierarchy of control, PPE should be the last option for controlling exposure.

Respirators should be:

- suitable for the conditions likely to be encountered
- selected according to the level of risk indicated by real-time monitoring.

The manufacture, use, care and maintenance of respiratory protective devices should be in accordance with Australian Standards AS/NZS 1715:2009 *Selection, use and maintenance of respiratory protective equipment* and AS/NZS 1716:2012 *Respiratory protective devices*.

9 Further information

This list is provided for general guidance and illustrates the variety of reference material available.

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Appendix 1 – Legislative provisions

The divisions of the Mines Safety and Inspection Regulations 1995 that are relevant to this guideline are listed below.

Part 9 Ventilation and control of dust and atmospheric contaminants

r. 9.11	Exposure standards
r. 9.12	Control of atmospheric contaminants
r. 9.13	Sampling of atmospheric contaminants
r. 9.14	Air in underground workplaces
r. 9.16	Air sources
r. 9.20	Ventilating fans and equipment
r. 9.21	Control of air distribution underground
r. 9.28	Ventilation plans for underground mines
r. 9.29	Monitoring of toxic, asphyxiant and explosive gases

Part 10 Specific requirements for underground mines

Division 4 Diesel units

r. 10.47	Terms use in this Division
r. 10.50	Registration of diesel units used underground
r. 10.51	Specifications and testing of diesel units
r. 10.52	Ventilating air requirements for diesel unit operations
r. 10.53	Exhaust treatment device
r. 10.54	Undiluted exhaust gas sampling

r. 10.55 Opacity of exhaust emission

r. 10.56 Testing costs, methods and equipment

r. 10.57 Records

Note: The only authorised versions of the Mines Safety and Inspection Act 1994 and regulations are those available from the State Law Publisher (www.slp.wa.gov.au), the official publisher of Western Australian legislation and statutory information.

Appendix 2 – Example checklists

A2.1 Overall checklist

The management of diesel emissions can best be achieved through a holistic approach, incorporating the following factors.

☐	**Adopt a coordinated and centralised plan of action** Appoint a program coordinator and gain commitment from all parties.
☐	**"Buy clean"** Select low-emission fleet equipment that is compatible with the intended operating environment. Compare engine types and operating characteristics. Consider exhaust treatment devices.
☐	**Scrutinise fuel and lubrication sources** Source low-contaminant fuel and lubricants for the diesel fleet. Only low sulphur fuels or biodiesel should be considered.
☐	**Establish baseline emissions for diesel fleet prior to use** Determine a diesel emission profile for each vehicle at the commencement of service. A variation in individual performance compared to similar items of the fleet may indicate potential problems.
☐	**Retro-fit exhaust emission treatment devices** Establish which fleet units require exhaust treatment devices to minimise emissions. It may be more practical to retire fleet items that are unable to meet the required standards rather than retro-fit treatment devices.

- [ ] **Implement a preventative maintenance program**

  Develop a program to ensure the ongoing maintenance and optimisation of diesel equipment. This includes ongoing diesel emissions testing and maintenance of exhaust treatment devices, if fitted. [see Section A2.2]

- [ ] **Establish the ventilation requirements**

  The ventilation officer should assess the available ventilation and implications for the proposed diesel fleet. Ideally, available air should exceed total diesel fleet requirements, otherwise utilisation of diesel equipment should be rationalised, matching equipment in use to available air.

- [ ] **Monitor vehicles and work environment**

  Conduct an ongoing monitoring program to evaluate vehicle performance, workplace atmosphere and exposure of workforce to diesel emissions.

- [ ] **Develop and implement training program**

  Training should ensure operators understand the objectives of the emission-reduction program, and the impact that certain driving techniques have on fuel consumption and diesel emissions. Maintenance personnel should be trained to maintain engines and exhaust treatment devices at optimum performance.

- [ ] **Evaluate exposure controls and PPE**

  Eliminating diesel emissions and reducing or controlling employees' exposure to diesel emissions are the primary objectives of the emission-reduction program. Evaluate solutions such as enclosed vehicle cabins and provision of suitable PPE for workers to address residual risks.

A2.2 Maintenance checklist

☐	**Air intake system** Is the air intake canister as tight as possible? Are seals and springs firm, with no leaks or blockages in hoses or connections? Are filters seated and fitted firmly?
☐	**Charger cooler** Is the charger cooler blocked or leaking? Has it been pressure-checked?
☐	**Exhaust system** Are “black witness marks” obvious? Do components move under load? Are there any blockages or restrictions?
☐	**Fuel and lubricant** Does the fuel have an ultra-low sulphur content? Do the fuel and lubricant additives meet specifications?
☐	**Fuel storage** Have the fuel and lubricants been checked for exposure to moisture or other contaminants?
☐	**Fuelling** Are vehicles refuelled at the end of shift or when the engine is cold?
☐	**Inventory** Are sufficient spare parts available?
☐	**Filters** If filters are cleaned and reused, is the cleaning technique verified as effective?
☐	**Tyres** Are tyres maintained (e.g. air pressure, tread) to optimise vehicle performance?

☐	**Tuning and electronic control unit (ECU) settings** Are engines configured and optimised to reduce emissions?
☐	**Throttle setting** Are throttles configured to minimise aggressive use?

Appendix 3 – Determining DPM as elemental carbon

The following procedure is approved by the State Mining Engineer for sampling and determining DPM as elemental carbon. It is aligned to the internationally recognised standard methods for measuring DPM, and may be used by ventilation technicians and officers at underground mine sites in Western Australia.

Reference methods

ASTM INTERNATIONAL, 2008, ASTM D6877.03:2008 Standard test method for monitoring diesel particulate exhaust in the workplace.

NATIONAL INSTITUTE OF OCCUPATIONAL SAFETY AND HEALTH, 2003, NIOSH Manual of Analytical Methods (NMAM), Fourth Edition: Method 5040 Diesel Particulate Matter (as Elemental Carbon).

NATIONAL INSTITUTE OF OCCUPATIONAL SAFETY AND HEALTH, 2003, NIOSH Manual of Analytical Methods (NMAM), Fourth Edition: Chapter Q – Monitoring of diesel particulate exhaust in the workplace.

Principle

In the recommended procedure, a personal sampling pump draws air through the sampling media, collecting the DPM onto a quartz filter. The filter is analysed for elemental carbon using a highly sensitive evolved gas analysis technique with thermal-optical analyser.

Sampling method

Sampling cassettes and holders

To sample DPM, a cyclone is recommended to separate the larger particulate from the respirable fraction, particularly where there is the potential for high dust loadings. Plastic cyclones are suitable for housing the recommended cassettes and sampling media.

Sampling media

The collection media consists of a heat-treated 37 mm-diameter quartz fibre filter. This enables the laboratory to take a portion of the filter (1.5 cm^2) for analysis. Depending on the cyclone chosen, the quartz fibre filter will be loaded into a 37 mm-diameter cassette with a stainless steel support pad (for use in the conductive plastic cyclone), or be available as a pre-loaded three-piece cassette (for use in the multiple inlet cyclone).

Considerations when selecting cassettes and holders

Option 1

The quartz fibre filter is manually loaded into the cassette and, depending on its type, the cyclone runs at a sampling rate of 2.2 L/min. The design of the cyclone allows the entire sampling train to be calibrated by attaching a hose from the inlet of the cyclone to the calibrator. The particle size allowed through the filter is about 7-10 μm so this option does not reduce all potentially contaminating material.

Option 2

The entire cassette can be purchased pre-loaded, and runs at a sampling rate of 1.7 L/min if used without a cyclone. These cassettes are the most expensive option and, if used without a cyclone, a separate cassette holder also needs to be purchased. This option uses a specific 1 μm cut to obtain a much cleaner sample for analysis.

A similar but slightly larger version of the conductive plastic cyclone in option 1, run at a sampling rate of 2.0 L/min, can also house the cassette. A cyclone should be used where sampling of larger particulates that can clog the impactor is likely.

Sampling requirements

Unless there are special circumstances, sampling times should be as long as is reasonably practicable (but not less than four hours) and should be representative of the working periods of individuals exposed.

Employees should keep the sampling head in their breathing zone, which is within 30 cm of their breathing area. Calibrate sampling trains before and after monitoring.

After sampling, replace the top piece of the cassette, if it has been removed, and pack securely for shipment to a laboratory accredited for the NIOSH 5040 method.

As good analytical practice, field blanks should also be run. Select ten per cent or a minimum of two filters or pre-loaded sampling cassettes from each batch of filters used. These should be submitted to the laboratory using the same procedures as for the sample filters, but omitting the sampling step.

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