Occupational Cancer Research Centre

CONTROLLING DIESEL PARTICULATE MATTER IN CONSTRUCTION

Occupational Cancer Research Centre Report

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Background

Diesel engine exhaust is a complex mixture of toxic gases and particulates produced from the combustion of diesel fuel (NTP, 2016). The exhaust can contain particulate matter, nitrogen oxides, carbon monoxide, polycyclic aromatic hydrocarbons, sulfur oxides, metals, and many other chemicals (IARC, 2013). The composition of the mixture varies depending on a number of factors including engine type, operating conditions, lubricating oil, additives, emission control systems, maintenance, and fuel composition (NTP, 2016). This report will focus mainly on the particulate matter component of diesel exhaust. Results from animal studies indicate that this component is more relevant to lung cancer outcomes than the gas phase component and the key studies of cancer in humans have focused on diesel engine exhaust particulate, measured as respirable elemental carbon (IARC, 2013).

Diesel engine exhaust is classified as a Group 1 *definite human carcinogen* by the International Agency for Research on Cancer. Exposure to diesel engine exhaust causes lung cancer, and there is limited evidence that it may cause bladder cancer (IARC, 2013). Cardiovascular disease is also linked to exposure to particulate matter air pollution, of which diesel emissions are a major contributor (Brook et al, 2010). Exposure to diesel engine exhaust can also cause eye, throat and bronchial irritation, light-headedness, nausea, coughing, phlegm, allergic reactions, or increased severity of allergic responses.

Diesel engines are widely used in construction for many different applications. Approximately 28,000 Ontario construction workers are estimated to be exposed to diesel engine exhaust (CAREX Canada, 2014). Almost all exposure occurs via inhalation. CAREX Canada estimates that approximately 95% of the construction workers occupationally exposed to diesel engine exhaust in Ontario are exposed at low levels, defined as using diesel equipment above ground, working near but not with diesel equipment, and working near traffic-related sources (CAREX Canada, 2014).

There is currently no occupational exposure limit for diesel engine exhaust that applies to the construction industry in Canada. In other jurisdictions or industries, diesel particulate matter regulations measure either total carbon, which is made up of organic carbon plus elemental carbon, or elemental carbon alone. Currently, elemental carbon is believed to be the best measure of diesel particulate matter, as it makes up the bulk of diesel particulate emissions, and is less susceptible to interference from other particulate sources in the workplace (HEI, 2015). In Ontario mines, regulation requires that the time-weighted average exposure of a mine worker to diesel particulate matter must be no more than 0.4 mg/m^3 total carbon, or that the elemental carbon multiplied by 1.3 is not more than 0.4 mg/m^3 (Occupational Health and Safety Act Reg. 854). However, based on current research this level does not sufficiently protect workers' health. For the construction industry, the Occupational Cancer Research Centre recommends introducing an exposure limit of 0.005 mg/m^3 measured as elemental carbon.

About the Diagram

This diagram showcases the control strategies available for diesel engine exhaust in the Ontario construction sector. It incorporates the Hierarchy of Controls, where control strategies are ranked from most effective (elimination or substitution) to least effective (personal protective equipment). The diagram also distinguishes between proactive controls (which eliminate or reduce diesel emissions *before* they enter workplace air) and reactive controls (which reduce the concentration of diesel emissions *already present* in workplace air, or reduce the likelihood that workers will inhale the emissions). Proactive controls are generally considered to be more effective than reactive controls.

An effective emissions control program utilises multiple controls from across the Hierarchy, and includes emissions monitoring to evaluate the effectiveness of the program.

Monitoring Emissions

While an emissions monitoring program does not actively lower emissions, it is important in order to ensure that diesel controls are working effectively and are sufficient for the amount of diesel exhaust being produced. Tracking emissions can be used to inform diesel control policies, especially when combined with vehicle and personnel tracking (Bugarski et al, 2011).

Diesel engine exhaust is a complex mixture, and there are a number of substances that can be monitored. Particulate matter (measured as total carbon or elemental carbon) is of high concern, but there are also a number of gases found in diesel emissions including carbon monoxide, carbon dioxide, nitrogen oxides, hydrocarbons, oxygen, and sulphur dioxide.

Emissions monitoring can include both undiluted emissions measurements and ambient air measurements. Undiluted emissions measurements include both 'tailpipe output' (emitted from tailpipe, downstream of aftertreatment systems) and 'engine out' (upstream of aftertreatment systems) emissions, and can help to identify and distinguish between engine maintenance issues and failures of emission control devices (Bugarski et al, 2011). These measurements can also help to estimate ventilation requirements. For more information on how to test for gases in undiluted emissions, see Bugarski et al, 2011 Section 2.4 and Ontario Ministry of Labour, 2014 (while these resources refer to underground mines, the monitoring procedures can be applied to construction in the absence of industry-specific guidelines).

Ambient air monitoring (personal and area sampling) indicates whether the overall diesel emissions control strategy is effective, sufficient, and functioning properly to ensure workers' health. There is currently no occupational exposure limit for diesel particulate matter that applies to the Ontario construction industry. In underground mines, Ontario Regulation 854 sets the maximum concentration of diesel particulate matter at 0.4 mg/m^3, measured as total carbon (Occupational Health and Safety Act Reg. 854). However, based on current research this level does not sufficiently protect workers' health. For the construction industry, the Occupational Cancer Research Centre recommends reducing diesel particulate emissions to 0.005 mg/m^3 measured as elemental carbon. Gases produced by diesel engines can be measured in a few different ways, including colorimetric dosimeter tubes and portable real-time continuous gas monitors (Bugarski et al, 2011). Occupational exposure limits for gases and other hazardous substances can be found in Ontario Reg. 833 (Occupational Health and Safety Act Reg. 833). For more information on sampling procedures for diesel particulate matter and gases in ambient air, see Bugarski et al, 2011 Section 4, and Ontario Ministry of Labour, 2015 (while these resources refer to underground mines, the monitoring procedures can be applied to construction in the absence of industry-specific guidelines).

Control Strategies in Construction

1. **Alternative energy**

Electric engines do not produce tailpipe emissions (100% reduction) and are therefore one of the best options for reducing diesel engine emissions and protecting workers' health (US Department of Energy, 2016). They also produce less noise and heat than diesel engines. Hybrid diesel-electric vehicles can significantly reduce emissions. An EPA-verified hybrid engine for non-road gantry cranes results in a 74% reduction in particulate emissions compared to a Tier 2 engine, and a 56% fuel economy improvement (US EPA, 2016a). A study by CANMET-MMSL demonstrated reductions between 25-40% for off-road mining equipment (Laverdure et al, 2011).

The cost of new electric equipment is high, but this cost may be somewhat offset by reduced fuel costs, as well as potentially lowered maintenance costs (Varaschin and De Souza, 2015). Eliminating diesel engines in favour of electric equipment also eliminates the need for further diesel emission controls.

2. **Replace or Repower old equipment**

The emissions reductions for replacing old equipment with newer diesel equipment, or repowering old equipment with newer engines depends on the original equipment, as well as the new engine. Emissions standards for new models of off-road diesel engines have been regulated in Canada since 2006. The Canadian regulations generally follow the US Environmental Protection Agency's tier system, which has emissions standards from Tier 1 up to Tier 4 (the current strictest standards). The emissions reductions when moving from older to newer engines can be significant. Repowering a 1975-1986 (unregulated) scraper with a Tier 1 or Tier 2 engine reduces particulate matter emissions by an estimated 62% or 81%, respectively (Scott et al, 2005). Tier 4 standards for off-road equipment reduce allowed particulate emissions by 50-95% (based on engine type) compared to previous standards (Diesel Technology Forum; US EPA, 2016c; MassDEP, 2008). It should be noted that field-tested emissions reductions were not available for off-road diesel equipment, but the changing standards give some idea of the significant impact of replacing or repowering old diesel equipment.

Replacing or repowering old equipment involves a significant upfront cost, especially if the entire vehicle is replaced. Repowering is the cheaper option. One large construction company found that off-road equipment repowers average around $100,000, including installation costs (Sturgess, 2012). However, price will vary based on the equipment and new engine. For example, the first repower of an unregulated D11 bulldozer with a Tier 2 engine cost $350,000; however replacement of the machine would have cost $2.2 million. Repowering a 300 horsepower 1987 model scraper with a Tier 4 certified 2012 engine costs approximately $90,000 (SBCAPCD, 2013). Repowering a D6H track-type tractor costs about $27,000 (US EPA, 2007).

Repowering can be a good option if the vehicle is in good shape, and is compatible with the new engine. Repowering can significantly increase the working life of the equipment, so higher horsepower machines that are generally more expensive to fully replace may also be good options for repowering (John Deere, 2017). Replacing or repowering the equipment can also have cost benefits in terms of decreased maintenance costs and increased efficiency.

3. Rebuild engines

Engine rebuilds are required as part of ongoing maintenance of diesel engines. However, when an engine is rebuilt, the engine can be upgraded by incorporating emissions-reducing parts. Manufacturers sometimes provide emissions upgrade kits that can be used during a rebuild for this purpose. Emissions reductions will depend on the engine and the kit. For example, Caterpillar produces an emissions upgrade kit that is verified by the EPA to reduce particulate matter emissions by 22% for certain models of off-road 1970-1995 year engines (US EPA, 2016a). The main components of the upgrade kit are a turbocharger, fuel pump/governor, fuel injection nozzles, and pistons/rings/liners (US EPA, 2016a).

Emissions upgrade kits are relatively cost effective, especially when installed during a regularly-scheduled rebuild. Incorporating an emissions reduction kit during a rebuild will increase the cost of the rebuild by several thousand dollars (US EPA, 2007).

4. Local Exhaust Ventilation (LEV)

Local exhaust ventilation (LEV) is an engineering control that captures emissions close to the source, before they enter the general atmosphere, and exhausts them to a safe area away from workers (Health & Safety Authority, 2014). Examples of LEV technology for diesel equipment include tailpipe exhaust extraction systems and stack exhaust hoses, in which tubing and fans are attached to the equipment's exhaust system to draw the emissions away from the work area (Safe Work Australia, 2015). The diesel emissions can be discharged to outdoor, unenclosed areas away from workers.

LEV may not be suitable for all applications due to the need for equipment mobility on many construction sites. LEV systems work well on stationary equipment, and longer-term tasks or projects. It is especially useful when diesel equipment is operated in enclosed structures such as buildings, parking garages, and tunnels, or in or near below-grade work such as excavations.

The effectiveness of LEV depends on many factors, including how it is designed and set up, the airflow, maintenance, and adherence to proper use (Health & Safety Authority, 2014). For more information on implementing LEV, see http://www.hsa.ie/eng/Publications_and_Forms/Publications/Occupational_Health/Local_Exhaust_Ventilation_LEV_Guidance.pdf.

5. Aftertreatment systems

Emissions reductions from aftertreatment systems will depend on the aftertreatment system chosen and the equipment they are installed on, among other factors. The choice of which aftertreatment system to use will depend on the engine and specific application, duty cycle, operating conditions, and the emissions reductions required. Examples of aftertreatment systems that decrease diesel particulate matter include:

- Diesel particulate filters (DPF): 80-99% particulate matter reduction (costs: $5000-$20,000)
- Flow-through filters (FTF): 50-75% particulate matter reduction (costs: $3000-$5000)
- Diesel oxidation catalysts (DOC): 20-50% particulate matter reduction (costs: $1000-$2000)

Crankcase emissions also contribute to overall diesel particulate emissions, and are not controlled by tailpipe aftertreatment systems. Uncontrolled crankcase emissions can represent 35% of total particulate emissions for earlier engine models, and higher percentages for newer engines with better tailpipe controls (Jaroszczyk et al, 2006). Crankcase emissions are even higher relative to tailpipe contributions when the engine is idling (Scott et al, 2005). Closed crankcase ventilation systems help control crankcase emissions, and can reduce overall particulate matter emissions by 10-15% (Diesel Technology Forum, 2006).

There are a number of aftertreatment systems aimed at reducing emissions of nitrogen oxides. These include:

- Exhaust gas recirculation (EGR): 50-90% NO_x reduction (cost: $13,000-$15,000)
- Selective catalytic reduction (SCR): 50-90% NO_x reduction (cost: $10,000-$50,000)
- Lean NO_x catalysts (LNC): 20-30% NO_x reduction

Both the US Environmental Protection Agency and the California Environmental Protection Agency offer lists of verified diesel emission control strategies:

- https://www.epa.gov/verified-diesel-tech/verified-technologies-list-clean-diesel
- https://www.arb.ca.gov/diesel/verdev/vt/cvt.htm

References:

- DPF: US EPA, 2007; Diesel Technology Forum, 2003; MassDEP, 2008; Diesel Technology Forum, 2006; Bugarski et al, 2009; Bugarski et al, 2006b; Bugarski et al, 2006a; Stachulak et al, 2006; Mischler & Colinet, 2009; Scott et al, 2005; US EPA, 2016; Bugarski et al, 2011
- FTF: MassDEP, 2008; Scott et al, 2005; Bugarski et al, 2011
- DOC: US EPA, 2007; Diesel Technology Forum, 2003; MassDEP, 2008; Diesel Technology Forum, 2006; Bugarski et al, 2009; Bugarski et al, 2006b; Mischler & Colinet, 2009; Scott et al, 2005; Bugarski et al, 2011
- EGR: Diesel Technology Forum, 2003; Diesel Technology Forum, 2006
- SCR: Diesel Technology Forum, 2003; Diesel Technology Forum, 2006; Scott et al, 2005; US EPA, 2016; Bugarski et al, 2011
- LNC: Diesel Technology Forum, 2003; Diesel Technology Forum, 2006; Scott et al, 2005; Bugarski et al, 2011
- Costs: US EPA, 2007; Diesel Technology Forum, 2003; MassDEP, 2008

6. Anti-Idling Technology

Anti-idling technology generally works by shutting off the engine after it has been idling for a set amount of time. Some diesel equipment comes already installed with features that will automatically shut off engines after a few minutes of idling – these features just need to be turned on (US EPA, 2007). Other technologies that reduce idling include those that provide services that would otherwise require the engine to be on, such as heat, air conditioning, or electricity (US EPA, 2016b). For example, auxiliary power units (APUs) provide power to the cab without running the engine, and are a good application if equipment is idled in order to maintain cab comfort (US EPA, 2007).

One study found that an for an uncontrolled 89 hp engine, operating at a load factor of 0.21, one hour of idling produces 13g of particulate matter, 155g of NOx, and 65g each of CO and CO2 (US EPA, 2007).

Costs for anti-idling technology for off-road equipment varies, but can range from $500-$9,000 (US EPA, 2007). Reducing idling can result in fuel cost savings, longer engine life, and reduced maintenance costs. To estimate potential savings from reduced idling, visit [http://www.ucair.org/wp-content/uploads/2013/05/Idling-for-Heavy-Duty-Vehicles.pdf.](http://www.ucair.org/wp-content/uploads/2013/05/Idling-for-Heavy-Duty-Vehicles.pdf)

7. Enclosed cabs

Enclosed cabs help to reduce diesel exhaust exposure to the vehicle operator. Properly functioning enclosed cabs can reduce diesel particulate and dust exposure by 90% or more (Bugarski et al, 2011). However, if cabs are not optimized, they can be less than 40% efficient in removing dust and diesel particulate matter (Bugarski et al, 2011). Factors that affect the proper functioning of cabs include use of recirculation filters, intake filter efficiency, cab integrity, open windows, etc. Having a heating and air conditioning unit within the cab, as well as prohibiting smoking in cabs can help to reduce open windows and increase cab effectiveness. Cabs can be retrofitted on to some older equipment, or included in newly purchased equipment. When deciding whether to implement enclosed cabs, space restrictions should be considered, if work will be done in confined spaces. Another consideration is that enclosed cabs do not reduce exposure to nearby workers.

8. Remote or tele-operation

Remote or tele-operating is control of equipment from a distance. Tele-operation allows the worker to operate a diesel engine from a safer location, such as in an area with better ventilation, or in an environmentally-controlled cab or control room (Fisher & Schnittger, 2012; Bugarski et al, 2012). This protects the operator from diesel engine emissions, as well as other hazards such as noise, dust, whole body vibration, injuries, and ergonomic discomforts (Paraszczak et al, 2015). Remote operation may be useful in excavation work or tunnelling, where the level of diesel engine exhaust may be high.

Tele-operation requires extra training for operators to ensure safe and effective use of remote equipment. Specialized equipment and technologies are also needed in order to implement tele-operation, and these devices may require maintenance by skilled personnel (Fisher & Schnittger, 2012).

9. General Ventilation

General ventilation is the flow of air into and out of a working area. It can include natural ventilation such as open doors and windows, or forced ventilation, where fans are used to move air through the space at a set rate. When diesel engines are operating in confined, enclosed, or below grade areas, it is especially important to ensure that enough ventilation is provided, or diesel fumes are otherwise controlled (HSE, 2006). The reduction in concentration of diesel emissions in the atmosphere due to general ventilation depends on the volume of clean air directed to the working area. Generally, forced ventilation will provide greater airflow than natural ventilation. Increasing airflow can be achieved by using higher horsepower fans or adding more fans in parallel. Increased airflow can also be achieved by improving the efficiency of the ventilation, by blocking air to nonessential areas, or through the placement of auxiliary fans to direct air toward working areas (Bugarski et al, 2011).

A benefit of general ventilation is that as well as helping to dilute diesel emissions, it can also help reduce the concentration of other hazardous substances, such as crystalline silica, paint fumes, or other chemicals.

10. Exhaust extenders

Exhaust extenders are used to redirect exhaust away from the operator or nearby workers. The location of the exhaust pipe can impact an operator's exposure (MSHA Toolbox). For instance, if a vehicle exhausts directly under or in front of the cab, operator exposure may be higher. Adding an exhaust extender may help to allow the emissions to become diluted before they enter the operator's breathing zone. However, little is known about the effectiveness of exhaust extenders in reducing exposure.

11. Preventive maintenance

Diesel emissions can increase significantly due to wear or breakdown of the engine components or aftertreatment systems. The impact on emissions will vary depending on the type of engine and the state of wear. One report for the Diesel Emissions Evaluation Program (DEEP) found that in test situations, depending on the engine design technology and condition, maintenance decreased particulate matter emissions by up to 55% (McGinn). Another study found that a basic tune-up reduced particulate matter emissions by 40% (Diesel Technology Forum, 2003). An EPA study of a 2000-year model on-road heavy diesel engine found significant particulate matter emissions increases for specific maintenance issues: clogged air filters caused a 40-50% increase; excess oil consumption resulted in over 100% increase; higher lube oil consumption caused up to 85% increase, minor ejector problems caused 35-75% increase; and nozzle hole wear in the fuel injectors resulted in up to 85% increase (US EPA, 2007). It should be noted that these emissions increases were not measured for non-road equipment, but give some idea of the benefits of proper maintenance for large diesel engines. Preventive maintenance programs should involve equipment inventory, usage tracking, knowledge of maintenance requirements for each engine, and routine performance checks. This tracking can be done manually or through specialized maintenance program software. Training operators to be able to identify signs of poor maintenance can also help avoid major engine failures.

A basic tuneup can cost in the range of $500-$2000 (Diesel Technology Forum, 2003). However, performing regular maintenance can save money by avoiding larger problems and engine malfunctions. Proper maintenance can also reduce fuel and oil consumption. Manual tracking of maintenance needs involves fairly low administrative costs. Software to track maintenance needs can be expensive (on the order of $100,000 to set up) (US EPA, 2007), but may be more practical for larger companies.

12. Idling policies

Idling policies set specific limits on the amount of time a vehicle can be left at idle. An idling policy should define warm-up and cool-down periods for diesel equipment, based on manufacturer's recommendations (US EPA, 2007). Generally, newer equipment requires almost no warm-up and cool-down time, so idling to avoid shutdown is unnecessary. Idling also puts wear on the engine and decreases engine life, increases fuel costs, and produces emissions. For an uncontrolled backhoe loader with an 89 horsepower engine operating under a load factor of 0.21, one hour of idling produces approximately 13 g of particulate matter, 155 g of nitrogen oxides, 65 g of carbon monoxide, and 65 g of carbon dioxide (US EPA, 2007).

Many operators may not be aware of the costs of idling. Educating operators about idling policies and why idling should be avoided is therefore an important component of idle-reduction policies (US EPA, 2007).

Instituting an idling policy has a low administrative cost, for operator training and tracking of idling.

13. Operator Training

Operator training to improve driving skills can reduce emissions by reducing fuel consumption, engine wear and maintenance needs, and time required to complete a task.

Other types of training can include awareness campaigns on the health hazards of diesel engine exhaust, proper respirator use, how to spot maintenance issues, costs of idling, effective use of enclosed cabs, and use and maintenance of emissions control technologies.

14. Scheduling and site planning

The goal of scheduling and site planning is to limit the number of vehicles producing diesel exhaust in a given area, or limit the number of workers who will be exposed to the exhaust. Examples include limiting the number of diesel engines operating in enclosed, confined, or below grade areas; locating diesel equipment away from fresh air intakes and windows; and avoiding running diesel engines at or near the edge of an excavation, as emissions can collect and accumulate (HSE, 2006; Scott et al, 2005).

As an example, the number of diesel vehicles operating in enclosed or below grade areas can be limited by setting up a system of tags, where vehicle operators must take a tag before entering an area. If no tags are available, the vehicle may not enter until another vehicle leaves (Bugarski et al, 2011).

Where possible, work with diesel equipment could be scheduled during off-peak times when fewer workers are in the area, especially if they are being used in enclosed or below grade areas (Safe Work Australia, 2015). Workers who have flexibility in their location on the worksite could be positioned away from in-use diesel engines. This decreases the number of workers potentially exposed, especially if diesel equipment operators can be protected by enclosed cabs (Bugarski et al, 2011). However, it is important to note that job rotation is not a viable control, as it increases the number of workers exposed to diesel engine emissions (Bugarski et al, 2011).

To protect the general public, access to walkways or areas near where diesel engines are working could be closed down, and foot traffic diverted to minimize the impact on those passing by (Safe Work Australia, 2015).

15. Respirators

Respirators can help reduce the wearer's exposure to diesel particulate and other hazardous substances, but should not take the place of other control measures. Other control measures should be used to achieve a safe level of exposures, and respirators should only be used to further reduce worker exposure. Respirators should therefore only be used as one component of an overall prevention and control program.

There are many different types of respirators. Air-purifying respirators filter contaminants from the air, while supplied air respirators provide fresh air from an uncontaminated source, such as a compressed air cylinder. Supplied air respirators typically give a higher protection than air-purifying respirators, and they also provide protection against concurrent exposures, but may be more cumbersome or restrict mobility, and are more expensive (IHSA, 2013).

Air-purifying respirators are further divided into powered (where a blower passes air through the filter) and non-powered (where air is drawn through the filter by the wearer's breath). Powered air-purifying respirators (PAPRs) generally give a higher level of protection than non-powered air-purifying respirators. The filters used in air-purifying respirators can be specific to a hazard or type of hazard, or may cover multiple exposures, and therefore need to be carefully selected for the environment (IHSA, 2013). Particulate filters may be described by their filter efficiency (from 95-99.97%) and oil resistance (N = not resistant to oil; R = somewhat resistant to oil; P = oil-resistant). If air-purifying respirators are used for diesel particulate matter, oil-resistance is recommended (Janssen & Bidwell, 2006).

Respirators have assigned protection factors (APFs) which represent the level of respiratory protection for a specific type of hazard that the respirator is expected to provide in the workplace when properly functioning, fitted, and used by trained wearers. Higher APFs represent a greater potential to filter out specific hazardous substances. Multiplying the APF by the occupational exposure limit for the hazard gives the maximum air contaminant level that the respirator is expected to provide protection against, under ideal circumstances. The US National Institute for Occupational Safety and Health (NIOSH) has assigned average APFs for different respirator types that range from 10 (for half-facepiece non-powered air purifying respirators), to 1000 (full facepiece PAPRs), to 10,000 (self-contained breathing apparatus, SCBA). The US National Institute for Occupational Safety and Health (NIOSH) provides a list of certified respirators which can be found here: https://wwwn.cdc.gov/niosh-cel/ (NIOSH, 2017).

However, actual respirator effectiveness under real workplace conditions can vary. Achieving adequate protection relies on choosing the correct type of respirator and filter media; appropriate maintenance, cleaning and storage; effective changeout schedules for any filters, canisters, or cartridges; proper fit testing; wearer training; and proper use by individual employees (Sargent & Gallo, 2003; Mayer & Korhonen, 1999). Respirators can impact visibility, comfort, and ease of breathing, and may be worn incorrectly in order to minimise these effects (Howie, 2005). Factors specific to the workplace, such as composition, concentration, and size distribution of the particulate may also affect respirator performance (Gao et al, 2015; Eninger et al, 2008; Reponen et al, 2011).

Poorly fitted respirators significantly increase worker exposure compared to properly fitted respirators (Zhuang et al, 2003; Gao et al, 2016; Coffey et al, 2004; Reponen et al, 2011). Therefore, fit testing should be performed at least annually, as well as whenever a new type of mask is used. Every type of mask will not fit every person. User seal checks should also be performed each time a respirator is used (Or et al, 2012; Zhuang et al, 2003).

Even for well-fitting respirators, most particle penetration occurs from leakage via the face seal (Sargent & Gallo, 2003; Cho et al, 2010), and passing a fit test does not necessarily guarantee the wearer's protection (Kim et al, 2015). Leakage around the respirator face seal can be exacerbated by facial hair; changes in weight; face shape or changes in face shape (e.g. due to dental work); movement of facial muscles; working posture; sweat or dust on the face; heavy breathing; and interference from other protective equipment such as hardhats (Sargent & Gallo, 2003; Kim et al, 2015; Mayer & Korhonen, 1999; Howie, 2005; Cho et al, 2010). Some of these factors, such as facial sweating and difficult working postures, may not be avoidable for construction workers.

When respirators are used in the workplace, a respirator program should be in place that includes all aspects of respirator use, including selection, maintenance, storage, cleaning, training, fitting, and supervision (MSHA, 2006).

Other Control Strategies

Alternative Fuels

Diesel fuel composition is regulated in Canada. For off-road engines, ultra-low sulphur diesel fuel (ULSD) containing less than 15 ppm sulphur has been required since 2012 (CAREX Canada, 2016). ULSD allows the use of many aftertreatment systems that cannot be used with higher-sulphur fuels (US EPA, 2007).

Apart from ULSD, a few alternative fuels have been tested for diesel equipment. The most common of these are biodiesel blends. Biodiesel blends of up to 20% can usually be used in most equipment with minimal modifications (Bugarski et al, 2011). However, biodiesel fuels can degrade more rapidly, may include impurities or varying quality, may not be compatible with all types of seals and gaskets, and have a higher gel point and so may not be practical in cold weather (Bugarski et al, 2011).

Generally, the use of biodiesel results in reductions in particulate matter mass, carbon monoxide, and hydrocarbons, but an increase in nitrogen oxides (Bugarski et al, 2011). The amount of particulate matter emitted when biodiesel is used is dependent on the engine, operating conditions, and blend (Bugarski et al, 2010). The US EPA has verified a 0-47% reduction in particulate matter emissions for biodiesel blends of 1-100%, for on-highway use (US EPA, 2016a). A study in an experimental mine setting found that biodiesel blends of 20-50% reduced elemental carbon by 33-66%, depending on the blend and type of biodiesel, but increased nitrogen dioxide (Bugarski et al, 2006b). Tests by NIOSH found that the mass concentration of diesel particulate matter decreased by approximately 50% when 100% biodiesel was used (Mischler & Colinet, 2009).

However, there are some concerns that biodiesel emissions may have increased toxicity compared to regular diesel emissions (Bugarski et al, 2011). Biodiesel may increase the fraction of particle-bound volatile organics and the number concentration of aerosols, especially under light-load conditions (Bugarski et al, 2010). Overall, there is little known about how the changes in physical and chemical properties when using biodiesel may affect health (Bugarski et al, 2010).

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