Natural Resources Canada
Ressources naturelles Canada

CANMET Mining and Mineral Sciences Laboratories
Laboratoires des mines et des sciences minérales de CANMET

DIVISION REPORT / RAPPORT DIVISION

AN OVERVIEW OF REGULATIONS TO CONTROL DIESEL EMISSIONS IN CANADIAN MINES

FEBRUARY 2002

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Project No. 601332
Report MMSL 02-043(OP,J)

Project: MMSL No. 601332

DIVISION REPORT MMSL 02-043(OP,J)

An overview of regulations to control diesel emissions in Canadian mines

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ABSTRACT: This paper reviews the current regulations for control of diesel emissions in Canadian underground non-coal mines. In general, provinces and territories govern the occupational health and safety regulations in Canada. This paper details similarities and differences in engine certification, ventilation requirements, fuel specifications, diesel particulate matter limits, and engine exhaust treatment system requirements. It also discusses the procedures required for the determination of engine ventilation rates for certification of diesel engines. The Exhaust Air Quality (EQI) criterion, incorporated into the Canadian Standards Association (CSA) standards, for the assessment of ventilation for certified engines will also be discussed. Recommendations are made to harmonize some of the regulations in Canada for diesel emissions control.

1 INTRODUCTION

Diesel equipment has been popular in Canadian mines for over forty years, mainly due to its characteristics of durability, fuel economy and reliability. In mines, diesel equipment is considered to be rugged, mobile and versatile, which enhances productivity. However, diesel equipment produces a number of harmful gaseous and particulate emissions, suspected to be potential human carcinogens. Therefore, diesel exhaust must be controlled to safe levels to limit workers exposure. The US and other international environment protection agencies have already promulgated stringent regulations for control of exhaust emissions from on-road and off-road applications. These regulations have driven innovative technical developments from the manufacturers. These developments include cleaner engines, more effective emission control systems and better fuel quality. In Canada, mine health and safety regulations fall under provincial jurisdiction, and hence diesel regulations vary from one province to the other.

Diesel exhaust is a complex mixture of toxic components containing both gaseous compounds and particulates. Further, the composition varies with the type of engine, fuel quality, engine duty cycle, maintenance, emission control technology, and operator's habit. The regulated gaseous components include carbon dioxide (CO_2), carbon monoxide (CO), nitric oxide (NO), nitrogen dioxide (NO_2), sulfur dioxide (SO_2) and hydrocarbons (HC). During the combustion process, the particulates produced are mainly composed of solid carbon cores. But, when released in the mine environment the particulates form chains or aggregates, adsorb volatile organic compounds, and become diesel particulate matter (DPM). DPM in a simplified form, can be expressed by the following equation:

$$DPM = TC + sulfates \quad (1)$$

where TC = EC + OC; TC = total carbon; EC = elemental carbon; and OC = organic carbon.

DPM also contains some other materials (metal ash, additives) which are in small quantities and are neglected in the above-simplified equation. The organic carbon is mostly unburned fuel and oil. In general, DPM is mostly (~85%) total carbon, and elemental carbon represents about 50% of the total carbon.

Table 1 lists DPM exposure limits and measurement methods used in some countries. DPM is measured as a separate parameter in several different methods. And, there is presently a lack of consensus on a specific parameter to be measured. Different regulatory agencies recommend measurement of different parameters.

In Canada, DPM is measured as respirable combustible dust (RCD). In this method, respirable dust is collected on a silver membrane filter using a 10-mm nylon cyclone set at a flow rate of 1.7 L/min. The portion of the collected sample that burns off at 400°C over a period of two hours divided by the total sampling flow volume is RCD (Gangal & Dainty 1993, Grenier & Butler 1996). A summary of DPM sampling methods is provided in a DEEP technology transfer initiative document (Grenier et al. 2001).

Table 1. Diesel particulate matter exposure limit in non-coal mines.

Country or Agency	Exposure limit mg/m^3	PM measured as/ measurement method
Germany, 1996		EC, coulometric
Tunneling & mines	0.3	
other work places	0.1	
Switzerland, tunneling	0.2	TC, coulometric
Canada (in most provinces, starting 1992)	1.5	RCD
CANMET Contract Study (proposed), 1990	0.5	DPM
MSHA, 2001	0.4 (July 2002) 0.16 (January 2006)	TC, NIOSH 5040
ACGIH, 2001, notice of intended changes	0.02	EC

2 EXHAUST QUALITY INDEX

A risk-free mine environment is most desirable from a health and safety point of view. However, such an environment is often difficult to achieve in a production mine. There is obviously a need to balance the costs and benefits when diesel equipment is introduced into a mine. A CANMET contract study (French & Mildon 1978, 1984 & 1990) reviewed the world literature relevant to potential health effects of diesel exhaust, and concluded that DPM is the pollutant of greatest concern followed by NO_2. The same study developed an EQI expression as a tool to estimate the relative toxicity of diesel exhaust emissions. This expression is heavily weighted for DPM, as it appears at three different places in the EQI expression. For this reason an EQI based testing protocol called 'MAPTEST' was developed to evaluate emissions performance of add-on systems including, fuel composition, additives, catalytic converters, diesel particulate filters (DPFs), and other treatment technologies (CANMET 1997). The EQI expression is given below (gases in ppm and DPM in mg/m^3 in the exhaust gas).

$$EQI = \frac{CO}{50} + \frac{NO}{25} + \frac{DPM}{2} + 1.5\left(\frac{SO_2}{3} + \frac{DPM}{2}\right) + 1.2\left(\frac{NO_2}{3} + \frac{DPM}{2}\right)$$

This expression is called Air Quality Index (AQI) when gases and DPM are measured in the ambient mine air. A maximum AQI value of three is recommended for exposure of miners to diesel pollutants.

The EQI expression is used as the exhaust toxicity criterion in the Canadian Standards Association (CSA) standards in order to define the exhaust dilution ratio and the ventilation for engine certification.

3 DIESEL REGULATIONS IN CANADA

In Canada, provinces and territories are responsible for occupational health and safety in mines. The exceptions are Crown Corporations and uranium mines that fall under federal jurisdiction. The certification of services for mining electrical and diesel equipment is provided by CANMET, a research branch of Natural Resources Canada (NRCan). The final approval, installation, application and use of the equipment are the responsibility of the mine inspectorates.

3.1 *Engine certification standards*

The preparation of Canadian standards for application to diesel equipment in mines began in the mid- to late 1970's and was an initiative of the provincial inspectorates acting in concert. The Chief Inspectorates, acting as a Canadian Standards Association (CSA) Steering Committee, agreed that a CSA Standards Committee should be formed with representatives from all parts of the industry. Two standards resulted from this work, and were published by the CSA, One for non-gassy underground mines (CSA 1990) and the other for gassy underground coal mines (CSA 1988). Both of the standards describe the technical requirements and procedures necessary for the design, performance, and testing of new or unused non-rail-bound, diesel-powered, self-propelled machines in underground mines. The working environment for gassy coal mines is characterized by the presence of methane gas and combustible dust. This paper will deal with health related regulations only pertaining to non-gassy underground mines. The main considerations can be described as:

- The fuel employed in certification tests conforms to CGSB standard (CGSB 1986, 1988 &1999)
- The sample engine submitted for approval should be tested on a dynamometer.
- For an engine approval, the undiluted exhaust gases shall contain not more than 2500 ppm of carbon monoxide, not more than 1500 ppm of oxides of nitrogen (NOx) and not more than 150 mg/m^3 of particulate.
- Exhaust treatment may be accomplished by a number of devices. Their application may result in reduced ventilation assessments.
- The dynamometer emission tests on a single example of the specified power package shall be performed. Such tests shall include, but are not necessarily be limited to, (a) confirmation of the maximum fuel rate setting, (b) determination of untreated engine emissions, and (c) exhaust

treatment device(s) performance evaluation, if applicable.

- The engine submitted for test shall be pre-run to the extent required to allow it to be operated immediately at full load and speed at the test facility.
- The emissions data during dynamometer testing is collected at steady-state operating points covering the engine power and speed ranges. The recommended ventilation rate pertains to the worst engine operating condition from an emissions toxicity standpoint.
- Ventilation air requirements are based on dilution ratio of EQI/3 and mass flow rate of exhaust gas.

The main feature of the CSA Standard is the application of a quality criterion by which to assess the comprehensive toxicity of diesel emissions in order to effectively prescribe ventilation requirements for a certified machine. The use of a comprehensive criterion is important because of the substantial changes in the individual concentrations of the toxic constituents produced by different engines.

3.2 *Ventilation requirements*

Table 2 summarizes engine certification and ventilation requirements for areas where diesel engines are used in non-coal mines.

Table 2. Diesel engine certification/ventilation requirements in Canadian mines.

Province/Territory	Certification standards		Notes
	CSA	MSHA	
British Columbia	Yes	--	Ventilation as per CSA standard
Alberta	Yes	--	Ventilation according to CSA standards, Minimum of 1.9 m^3/kW.s at active headings
Saskatchewan	--	--	Minimum ventilation 0.063 m^3/kW.s (3.8 m^3/kW.min)
Manitoba	Yes	Yes	Ventilation as per CANMET or MSHA standards For non-approved engines ventilation 0.092 m^3/kW.s (5.5 m^3/kW.min) For multiple-engines, ventilation using the 100/75/50 rule with a minimum of 0.045 m^3/kW.s (2.7 m^3/kW.min)
Ontario	--	--	Minimum ventilation 0.06 m^3/kW.s
Quebec	Yes	(see notes)	Ventilation as per CANMET or Part 31/32 of MSHA For non-approved engines ventilation 0.092 m^3/kW.s (5.5 m^3/kW.min) For MSHA engines, ventilation with 100/75/50 rule and a minimum of 0.045 m^3/kW.s (2.7 m^3/kW.min)
New Brunswick	Yes	Yes	Certification for engines above 75 kW required Minimum ventilation 0.067 m^3/kW.s (4 m^3/kW.min)
Nova Scotia	Yes	Yes	or a certificate that engine meets various conditions Minimum ventilation 0.06 m^3/kW.s
Newfoundland & Labrador	Yes	Yes	Ventilation as per CANMET or MSHA standards For multiple-engines, ventilation using the 100/75/50 rule with a minimum of 0.047 m^3/kW.s
Northwest Territories and Nunavut	--	--	Minimum ventilation 0.06 m^3/kW.s
Yukon		(see notes)	Requires approval number by an approved testing laboratory Minimum ventilation of 0.051 m^3/kW.s (2.3 m^3/HP.min) plus normal requirements of the mine

These requirements vary from province to province. The ventilation requirements are based on a fixed quantity of air per engine unit power, or determined during an engine certification using CSA (CSA 1988, CSA 1990) or MSHA (MSHA 1995, MSHA 1996) standards or a combination of two or all of these above requirements. MSHA ventilation rates are based on the amount of fresh air needed to dilute CO, CO_2, NO and NO_2 in the undiluted exhaust gas to a prescribed value when the engine is operated at the worst emission condition. CSA ventilation rates are calculated by multiplying the dilution ratio of EQI/3 with the exhaust gas flow rate. The prescribed ventilation rate pertains to the worst engine operating condition from an emissions toxicity standpoint, therefore represents a maximum value.

3.3 *Diesel fuel standards*

In Canada the Committee on Middle Distillate Fuels of the Canadian General Standards Board (CGSB) prepares standards for diesel fuel. The specified fuels are hydrocarbons that may contain additives designed to improve their handling characteristics or performance including diesel ignition quality, low-temperature flow properties, storage life, static charge dissipation, haze dissipation, corrosion inhibition and lubricity. The specified fuels are a stable homogenous liquid, free from foreign matter likely to clog filters or nozzles, or damage equipment. There are two standards for diesel fuels used in mines, one is Mining Diesel Fuel standard (CGSB 1986, 1988 &1999), and the other is Automotive Low Sulfur Diesel Fuel standard (CGSB1993). Both of the standards specify limiting values of fuel specifications and approved test methods. Table 3 compares sulfur and flash point for the specified standards. Fuel sulfur content and flash point are the fuel properties mostly specified in mine regulations. In these standards fuel sulfur varies from a low value of 0.05% by mass to a high value of 0.5% by mass, and flash point varies from 40°C to 52°C.

Table 3. Fuel sulfur and flash point specifications.

Fuel Standard, type	Maximum sulfur % by mass	Minimum flash point °C
CAN/CGSB-3.16-M86/M88, Regular	0.5	40
Special	0.25	52
CAN/CGSB-3.16-99, Special-LS	0.05	52
CAN/CGSB-3.517-93, A-LS	0.05	40

Table 4 summarizes the fuel quality requirements for diesel engines in Canadian mines. Some jurisdictions specify fuel requirements by the maximum value of fuel sulfur and by the minimum value of flash point. In these cases fuel does not have to be covered by any fuel standards, and therefore, does not control other fuel properties that are important for better emissions. The fuel sulfur varies from a value of 0.05% by mass to 0.5% by mass, while flash point varies from a value of 40°C to 52°C. There is a quite a large variation in fuel sulfur content. It should be noted that low fuel sulfur reduces both SO_2 and DPM concentrations in the environment, and also increases the effectiveness of emission control technologies in reducing DPM. For example, a reduction in fuel sulfur from 0.25% by mass to 0.05% by mass reduces the sulfate fraction of the DPM by 80% (Gangal 1999). Similarly, the minimum ventilation specified for CANMET - approved engines for a fuel sulfur of 0.25% by mass,

Table 4. Diesel fuel requirements in Canadian mines.

Province/Territory	CAN/CGSB Standards	Sulfur, maximum % by mass	Flash point °C
British Columbia	Yes	as in CAN/CGSB-3.16-M86, Mining Diesel Fuel-Special Type	
Alberta	Yes	as in CAN/CGSB-3.16-M88, Mining Diesel Fuel	
Saskatchewan	--	0.5	52
Manitoba	Yes	as in CAN/CGSB-3.16-99, Mining Diesel Fuel, Special-LS, or CAN/CGSB-3.517-93, Automotive Low Sulfur Diesel Fuel, type A-LS	
Ontario	Yes	as in CAN/CGSB-3.16-99, Mining Diesel Fuel, Special-LS, or CAN/CGSB-3.517, Automotive Low Sulfur Diesel Fuel, type A-LS	
Quebec	--	0.05	--
New Brunswick	--	--	--
Newfoundland & Labrador	Yes	as in CAN/CGSB-3.16-M88, Mining Diesel Fuel	
Nova Scotia, Yukon, Northwest Territories and Nunavut	--	0.25	52

can increase by 30% compared to that of fuel sulfur of 0.05% by mass (Gangal 1999).

3.4 *Exposure limits for gases*

Table 5 summarizes the exposure threshold limit values (TLV)-time weighted average (TWA) limits (ACGIH 2001) for the selected diesel exhaust gases.

Table 5. Exposure limits for selected diesel exhaust gases (ACGIH 2001).

Substance	TLV-TWA ppm	Critical health effects
CO	25	Anoxia, CVS, CNS, reproductive
CO_2	5000	Asphyxiation
NO	25	Anoxia, irritation, cyanosis
NO_2	3	Irritation, pulmonary, edema
SO_2	2	irritation

These ACGIH limits are intended for use in the practice of industrial hygiene as guidelines or recommendations in the control of potential health hazards and for no other use. However, various jurisdictions apply these limits to the workplace exposure. These limits are for a conventional 8-hour workday and 40-hour workweek. In Canadian mines, gas concentration measurements in the diesel areas of the mine are required and recorded. However, the frequency of measurements and maximum allowable limits vary from jurisdiction to jurisdiction. The province of Manitoba and Newfoundland & Labrador require that contaminants in the mine atmosphere should not exceed the TLV's as established by ACGIH. Other provinces also require similar limits but vary from jurisdiction to jurisdiction and are not listed in this paper.

3.5 *Exposure limits for diesel particulate matter*

Exposure limits for diesel particulate matter in most Canadian mines (British Columbia, Ontario, Quebec, New Brunswick, Nova Scotia, Northwest Territories and Nunavut) are set at 1.5 mg/m^3 measured as RCD. It is worth noting that the province of British Columbia was the first jurisdiction in Canada to legislate exposure limit in mines at 1.5 mg/m^3 RCD (British Columbia 1992). Later on many other provinces and territories legislated the same exposure limit in their jurisdictions. It should be noted that the province of Manitoba, and Newfoundland & Labrador regulations specify that the concentration of contaminants in the mine atmosphere does not exceed the ACGIH TLV's. Currently, there is no ACGIH adopted TLV for DPM but, a value of 0.02 mg/m^3 as EC is on the notice of intended changes (ACGIH 2001). At present, Alberta, Saskatchewan and Yukon do not have any requirements for DPM monitoring.

3.6 *Engine exhaust treatment systems*

Some of the provinces and territories require that diesel equipment must be equipped with an exhaust treatment device (Table 6).

Table 6. Engine Exhaust treatment system requirements in Canadian mines.

Province/Territory	Requirements
Saskatchewan	requires exhaust gas scrubber of a type and size approved by the chief inspector
Quebec	requires a device for purifying or diluting exhaust gases
New Brunswick	requires a notice and information on exhaust conditioning equipment specifications
Nova Scotia	engine to be maintained to prevent the emissions of black smoke, except at startup, and sparks or flames
Newfoundland & Labrador	engines, exhaust control devices, machines, catalysts and additives etc. are in accordance with National Standards CAN/CSA-M424.2-M90 (non gassy)
Yukon	requires that locomotives or equipment are equipped with an efficient scrubber for exhaust gases

Currently, there is no requirement for device performance verification. However, the devices are to be maintained properly.

4 DISCUSSIONS AND CONCLUSIONS

It is very clear that current occupational regulations for diesel exhaust control in Canadian mines vary widely, especially in the area of engine ventilation requirements, fuel quality and DPM exposure. It is well known that the exhaust gas emissions vary from engine to engine, therefore, ventilation to dilute exhaust gases should also vary in order to have good quality mine air. Similarly, a fixed ventilation rate per unit of engine power may be a good rule of thumb for general mine ventilation planning, but this rule does not encourage improvement of equipment from a pollution generation point of view, and provides no incentive to employ improved control technology. Further, good quality low sulfur fuel reduces SO_2 concentration and particulates, and enables the application of control devices to reduce diesel pollutants.

In general, ventilation has been the primary means to control and dilute exhaust in mines. But, it is beneficial to consider application of clean technologies (e.g. cleaner engines, good quality fuels, emission control devices). These technologies alone or in combination can drastically reduce pollutants in mines. Increased ventilation alone is expensive and can not be taken a primary means to control pollutants in mines.

5 RECOMMENDATIONS

Mine regulations should encourage use of (a) certified engines and prescribed ventilation rates based on air quality criterion to enable mine operators to select the best diesel equipment for their application, (b) low sulfur fuel that are based on a standard to ensure the consistency of fuel quality, (c) emission control technologies that have been verified by accredited laboratories to ensure the control of all regulated pollutants, and (d) proper maintenance program for diesel equipment.

Given the recent initiatives in the U.S. and the existing regulations in Europe, a review of the allowable DPM exposure limit is required in Canada. Finally, the above mentioned diesel related regulations should be harmonized in Canada to ensure good quality of air for mine workers across the country.

REFERENCES

ACHIH 2001. *Threshold limit values for chemical substances and physical agents*. Cincinnati: ACGIH.

British Columbia. 1992. *Health, safety and reclamation cod for mines in British Columbia*. Resource Management Branch, Ministry of Energy, Mines and Petroleum Resources, Victoria, British Columbia, Part 6, section 6.22.2.

CANMET. 1997. Manufacturer's protocol for exhaust systems testing (MAPTEST), Natural Resources Canada, Document No. MMSL 97-064 (CR).

CGSB.1986, 1988 & 1999. *Mining diesel fuel*. CAN/CGSB-3.16-M86, CAN/CGSB-3,16-M88 & CAN/CGSB-3.16-99, published by the Canadian General Standards Board, Ottawa, Ontario, Canada.

CGSB. 1993. *Automotive low sulfur diesel fuel*. CAN/CGSB-3.517-93, published by the Canadian General Standards Board, Ottawa, Ontario, Canada.

CSA. 1988. *Flameproof non-rail-bounded diesel-powered machines for use in gassy underground coal mines*, CAN/CSA-M424.1-88, published by the Canadian Standards Association, Toronto, Ontario, Canada

CSA.1990. *Non-rail bounded diesel-powered machines for use in non-gassy underground mines*, CAN/CSA-M424.2-M90, published by the Canadian Standards Association, Toronto, Ontario, Canada.

French, I.W. & Mildon, C.A.1978, 1984 &1990. *Health implications of exposure of underground workers to diesel exhaust emissions*, CANMET Contract Report Nos. 23SQ.23440-9-9142, 14SQ.23440-1-9003, 23SQ.23440-2-9062, o9SQ.23440-7-9042, Energy, Mines & Resources Canada, Ottawa.

Gangal, M.K. & Dainty, E.D.1993. Ambient Measurement of diesel particulate matter and respirable combustible dust in Canadian mines. *Proc.of the 6th US mine ventilation symposium*, Salt Lake City, Utah, USA: 83-89.

Gangal, M.K. 1999. The impact of new technologies on diesel emission control. *Proc. Mining Diesel Emissions Conference*, Toronto, Ontario, 1999.

Grenier, M & Butler, K. 1996. Respirable combustible dust sampling and analysis protocol, CANMET, Natural Resources Canada, Document no. MRL 96-029(TR).

Grenier, M et al. 2001, Sampling of diesel particulate matter in mines, DEEP technology transfer initiative report. CANMET, Natural Resources Canada, Document no. MMSL 01-052 (TR).

MSHA 1995. Diesel mine locomotives, Mobile diesel-powered equipment for non-coal mines, *30CFR, Parts 31 and 32*, Superintendent of Documents, Washington, DC, USA.

MSHA 1996. Approval, exhaust gas monitoring, and safety requirements for the use of diesel-powered equipment in underground mimes, final rule. *30CFR Parts 7, subpart E, category B engines*, Superintendent of Documents, Washington, DC, USA.