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SUGGESTED MODIFICATIONS TO THE NON-COAL MINE DIESEL STANDARD - CSA M424.2

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SUGGESTED MODIFICATIONS TO THE NON-COAL MINE DIESEL STANDARD CSA 424.2

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SUMMARY

Requests and suggestions from labour, a provincial inspectorate and mine operators for amplification of Clause 5.4 of CSA Standard CSA M424.2 for diesels in non-coal mines, resulted in the analysis and recommendations given in this report.

The first request was the definition of relative emissions performance of devices incorporated into the exhaust systems of diesel machines. The table and text providing relative factors are incorporated into suggested Clause 5.4 of the Standard in Appendix III of this document.

The second request was for amplification and definition of the on-site factors which could be used to reduce the **maximum** ventilation prescribed for a given vehicle according to the standard. The table and text are incorporated into suggested Clause 5.5 of Appendix IV of this document.

An assumed array of ventilation reduction factors for possible mine site conditions resulted in a combined reduction factor of 47% of the worst case ventilation for the F6L714 engine assessed by the certifying process. This factor yielded a brake specific ventilation of 97.2 cfm/bhp.

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KEY WORDS: diesels, mine ventilation, certification & standardization

MODIFICATIONS PROPOSÉES À LA NORME 424.2 DE L'ACNOR CONCERNANT LES MOTEURS DIESEL UTILISÉS DANS DES MINES AUTRES QUE DES MINES DE CHARBON

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RÉSUMÉ

Par suite de demandes et de suggestions présentées par des exploitants de mines, un service provincial d'inspection et un syndicat, en vue de faire élaborer plus en détail la clause 5.4 de la Norme M424.2 de l'ACNOR visant les moteurs diesel utilisés dans des mines autres que des mines de charbon, vous trouverez, dans le présent rapport, une analyse de la question et les recommandations formulées.

La première demande visait à faire déterminer le rendement relatif, quant au contrôle des gaz d'échappement, des dispositifs intégrés aux systèmes d'échappement de l'équipement à moteur diesel. Le tableau et le passage du rapport présentant les facteurs relatifs sont intégrés au projet de clause 5.4 de la Norme, tel que présenté à l'annexe III du document.

La deuxième demande visait à faire déterminer et exposer en détail les facteurs inhérents aux sites, qui pourraient être utilisés pour réduire l'aérage **maximum** que la norme prescrit pour un véhicule donné. Le tableau et le passage du rapport ayant trait à cette question sont intégrés au projet de clause 5.5 présenté à l'annexe IV du document.

Un ensemble de supposés facteurs de réduction de l'aérage, applicables à des conditions possibles dans des mines, a donné un facteur combiné de réduction de 47 % de l'aérage le plus mauvais relativement au type de moteur F6L714 évalué dans la cadre de l'exercice d'homologation. Ce facteur a permis d'établir à 97,7 pi^{3}m/pf l'aérage spécifique au banc d'essai de puissance.

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MOTS CLEFS : diesel, aérage de mine, homologation et normalisation

SUGGESTED MODIFICATIONS TO THE NON-COAL MINE DIESEL STANDARD CSA M424.2

INTRODUCTION

At the meeting of the Mining Legislative Review Committee (MLRC composed of OMOL, labour and industry) in North Bay on January 16/90, several suggestions regarding changes to CSA Standard M424.2 (1) were made. It was agreed that additions would be proposed for clause 5.4 in order to give examples of potential ventilation reductions resulting from the application of various treatment devices designed to reduce the toxicity of the emissions. In addition, it was requested that a clause 5.5 be added in order to provide quantitative values for the effects of site-specific features listed in clause 5.4.

A suggested protocol for the ultimate modification of the Standard to incorporate these suggestions, is as follows: (1) write the requested clauses, (2) circulate these suggested clauses among the MLRC first to gain its approval, (3) circulate these among the CSA Technical Committee members for their consideration, suggestions and ultimate approval, (4) call a meeting of the Technical Committee to formally approve such changes to the document.

This report outlines the first of the above steps.

CALCULATIONS OF EMISSIONS PERFORMANCE

General

Clause 5.4 of (1) specifies the ventilation recommendation for a certified engine. The question is - what ventilation reductions relative to untreated exhaust are potentially available if emissions reduction devices are applied to the engine in question?

CANMET has determined the performance of such devices from both in-house as well as contracted-out investigations. The performance of two engines - the Deutz F6L 714 and DDAD 8V71N were detailed in CANMET Report MRL 89-101 (OP), entitled "Comparison of the Ventilation Prescription Criteria for Certification of Diesel Engine-Equipped Mining Machinery" (2). This performance table is given in Appendix I and the calculations made below pertain to the performance of the Deutz engine (contract 7-9097). An early CANMET effort to define the performance of treatment options using the EQI was given in (3).

The following re-examines the changes in performance resulting from the application of add-on devices to a Deutz engine because this type is most commonly used underground in Canada.

The add-on devices most commonly employed to reduce diesel emissions toxicity, in order of frequency of application, are: (1) catalytic purifiers, (2) exhaust diluters, (3) ceramic filters, and

(4) water scrubbers. The first is almost universally applied, the second is common, the third has only been recently introduced, and the fourth is almost never applied because it is labour intensive.

The diluter does not alter the emissions, it simply prevents undiluted exhaust streams from causing unduly high exposures to machine operators, i.e. it in effect increases the local ventilation distribution efficiency (i.e. a diluter could reduce factor #2 of Table 3 in Appendix IV particularly for the LHD). It is therefore not included in the following treatment analyses.

In general, the original EQI expression, used as the exhaust toxicity criterion in CSA Standard M424.2 (1) in order to define the exhaust dilution ratio, is defined as follows (note that the additional H_2SO_4 term was included as an option in the text of the original IW French equation, if circumstances allowed its measurement):

$$EQI = \frac{CO}{50} + \frac{NO}{25} + \frac{soot}{1.5} + \frac{H_2SO_4}{1.0} + 1.5\left[\frac{SO_2}{3.0} + \frac{soot}{1.5}\right] + 1.2\left[\frac{NO_2}{3.0} + \frac{soot}{1.5}\right]$$

where the gas concentrations are measured in ppm and the soot and H_2SO_4 in mg/m3. The ventilation equation, as recommended in the same Standard (1), is:

$$\text{ventilation} = \frac{\text{engine dry gas rate X dilution ratio}}{\text{3600 X air density}}$$

Using these relationships, the calculations of Appendix II were performed and the results incorporated in Table 1 below.

Calculation of Bare Engine Performance

The emissions performance of the untreated exhaust option is derived from (2) and reproduced in Appendix I. The data for this study is calculated in Appendix II and recorded in Table 2.

Calculation of Catalytic Purifier Performance

In general, catalytic purifiers have the following performance characteristics:

(1) A catalyst always improves the combustion of CO to CO_2, and exhaust-borne hydrocarbons to CO_2 and water. Some catalysts have been shown to strip off and combust some of the hydrocarbons adsorbed onto the soot. With Deutz engines, CO combustion in catalysts is a modest advantage because so little CO is produced by the engine.

Table 1 - Comparative Performance Evaluations of Diesel Emissions Toxicity Reduction Devices

item	units	Deutz engine	catalyst equipped		filter	scrubber baffle	scrubber venturi
CO_2	%	10.0	10.0		10.0	10.0	10.0
ass'd catalyst CO efficiency	%	-	80		-	-	-
CO	ppm	147	30		162	147	147
NO	ppm	552	552		552	552	552*1
NO_2	ppm	10	10		10	10	10
SO_2	ppm	87.2*1	69.8		87.2	26.2	61.0
H_2SO_4	ppm	-	17.4		-	-	-
	mg/m^3	-	76.2		-	-	-
soot	mg/m^3	59.5	59.5		6.0	41.7	17.9
SO_2 Conversion		-	yes	no	-	-	-
EQIgas		28.4	-	-	-	-	-
dilution ratio		28.4	-	-	-	-	-
EQIsoot		151.4	-	-	-	-	-
dilution ratio		75.7					
EQIoverall	-	219	285	208	88	145	104
dilution ratio		73.0	-	-	-	-	-
ventilation (EQIoverall)							
calculated	kcfm	21.2	27.5	20.1	8.5	14.0	10.0
recommended	kcfm	21.2	27.5	20.1	14.8	17.6	15.6
BSV	cfm/bhp	159	207	151	112	132	117
relative vent factor		1.00	1.30	1.00	0.70	0.85	0.75

*1 0.2% sulphur in fuel assumed

Table 2 - Water Scrubber Performance Documentation

scrubber	conventional % removal	conventional optimized % removal	venturi engine conc	venturi engine + venturi conc	venturi % removal
reference	(4)	(4)	(5)	(5)	
CO_2	0	-	6.5 %	6.5 %	0
CO	0	-	199 ppm	194 ppm	0
NO	0	-	578	523	0*1
NO_2	0	-	25	39	0
SO_2	61-79	-	89 ppm	62 ppm	30
SO4	37	-	0.30 mg/m^3	0.04 mg/m^3	87
HC	20	-	191 ppm	154 ppm	19
soot	18-31	40	98 mg/m^3	26	73

*1 the actual 7% reduction is negligible; a zero value is assumed

(2) Some catalyst formulations cause the conversion of NO to NO_2 which is undesirable, while under some conditions, the positive reverse characteristic applies. No such conversions have been assumed for this work.

(3) Some catalysts cause the conversion of SO_2 to SO_3 producing H_2SO_4, or acid gas, in the emissions. In the calculations below, a relatively low conversion percent has been assumed. This is a negative characteristic. However, it has proven difficult to measure airborne H_2SO_4 underground (6), so that it is difficult to assess the impact, if any, on the workers.

(4) Some catalysts cause reactions which can result in high Ames mutagenic responses, suggestive of potential trouble from a carcinogenic point of view. A catalyzed pelletted purifier, now infrequently used, was so tested years ago (7). This led some to think that mutagenic tests on new catalyst prepara tions should be a part of the certification processes.

(5) Some recent (last 5 years) catalytic preparations, produced by three major manufacturers, have been shown to minimize both mutagenic response and conversion of SO_2 to SO_3, without seriously affecting other aspects of performance. It is not certain that it is these preparations which are incorporated into the catalyst units presently being sold.

(6) Generally, catalysts reduce the diesel smell to a more pleasant and more acceptable odour.

(7) The performance of the catalysts universally varies with exhaust temperature and oxygen concentrations. The lower the temperature, the less catalytic action. For example, a cold exhaust machine might convert as little as 20% of the CO to CO_2, and a hot exhaust machine as much as 90% assuming the available oxygen to be sufficient. The engine cycle chosen was that of an LHD at relatively high exhaust temperature. Therefore, a high CO conversion has been employed.

These factors affect the assessment of the emissions of a catalyst-equipped engine. The calculations of Appendix II represent an effort to assess the impact of these factors and arrive at a representative performance for comparison purposes making the following specific assumptions:

(1) 80% CO catalyst conversion efficiency at high load
(2) no NO or NO_2 conversions by catalyst
(3) soot limit value is 1.5 mg/m^3 (2.0 applies to RCD)
(4) the catalyst EQI includes the additive term $H_2SO_4/1.0$, or not (options in Table 1), and,
(5) 20% SO_2 catalyst conversion efficiency to H_2SO_4
(6) 0.2% sulphur in the fuel

From examination of the results in Table 1, it seems both simple and reasonable to assume that in general the catalytic purifier does not significantly affect the emissions. Therefore, this equal ventilation conclusion is incorporated into Table 1, indicating emissions reduction device performance recommended for addition to the Standard noting that this might not be true in the case of every catalytic unit.

Calculation of Ceramic Filter Performance

The essential action of the filter is to remove 90% of the soot. In so doing, it slightly increases the the CO concentration because the soot combustion reaction is not 100% complete. For non-catalyzed filters these are the major changes that occur.

The calculations of Appendix II indicate substantial ventilation reductions if the soot is essentially removed by the filter. It is not recommended that the entire reduction be implemented. Rather, it is recommended that only 50% of the ventilation reduction due to filter performance be applied in practice. This provides potential operating savings and thus an incentive to develop and apply new technology, while at the same time providing a significantly improved mine air quality and a factor of safety.

Therefore, the recommended filter ventilation is 14,832 cfm for this equipment option and the brake specific ventilation is 112 cfm/bhp. Note that this latter value just exceeds the 100 cfm/bhp ventilation regulation used in Ontario, even though only half the possible ventilation reduction has been included.

Calculation of Water Scrubber Performance

Water scrubbers, once popular in the non-coal mining industry, are now infrequently applied because of the labour intensive aspect. On the other hand, a properly maintained and replenished water scrubber can remove substantial amounts of toxic diesel emissions.

CANMET studies have shown that soot removal varies from 10 to 40% in simple baffle-type wet scrubbers, and some removal of the acid gases (SO_2 and NO_2) also occurs. The CANMET venturi scrubber improves this performance by increasing soot removal to as much as 70%, plus some of the acid gases as well. Neither scrubber removes substantial amounts of NO, and they remove none of the CO and CO_2.

These and other scrubber performance results are given in Table 2.

Summary of Emissions Performance Results

The bottom line of Table 1 indicates the relative ranking of the several emissions reduction devices considered in this analysis. These are listed in order from greatest to least in Table 3 from a ventilation point of view. Considering the full ventilation reduction based on an AQI = 3, the ceramic filter requires 40% of the untreated engine ventilation (full benefit or credit) , and applying the 50% benefit (or credit) recommendation, the filter requires 70%. All others lay in between. The latter rule gives

Table 3 - Order and Magnitude of Ventilation Recommendation

order	option		ventilation rate (cfm)	relative factor (-)	safety factor (-)
1	catalyst - 20% SO_2 conversion		27,500	1.30	1.00
2	Deutz F6L 714 engine		21,200	1.00	1.00
3	catalyst - no SO_2 conversion		20,100	0.95	1.00
4	baffle scrubber	- 50% reduction	17,600	0.83	1.26
		- 100% reduction	14,000	0.66	1.00
5	CANMET venturi	- 50% reduction	15,600	0.74	1.57
		- 100% reduction	10,000	0.47	1.00
6	ceramic filter	- 50% reduction	14,800	0.70	1.75
		- 100% reduction	8,500	0.40	1.00

equal benefit to labour and management. This approach also provides a safety factor (i.e. an AQI less than the limit of 3.0), varying from 1.25 to 1.75 for the water scrubbers and filter. On the other hand, applying the full ventilation benefit (AQI = 3) would still provide an environment, the individual constituents of which, would not in general exceed the current TLVs, and therefore be deemed a suitable environment.

The safety factor approach may prove to be helpful because of the possibility of reduced soot levels being prescribed by OSHA/MSHA as a result of their intensive consideration of the impact of whole diesel exhaust on health.

These ventilation factors have been placed into a suggested clause for the CSA metal mine standard, CSA M424.2, in Appendix III.

DISCUSSION OF ON-SITE VENTILATION-ALTERING FACTORS

General

Clause 5.4 of CSA Standard M424.2 (1), lists several on-site factors which are site-specific, and which cannot be known at the certification investigation stage. A single certified machine may be used in various, considerably differing circumstances. It follows then, that the maximum recommended ventilation rate specified for the certified machine could be reduced for the specific circumstances of use by consultation between the regulatory authority and the operator. The following discussion provides, as requested, some guidance with respect to the possible variation of these factors.

Altitude Variations

Air density varies with altitude; for example, at 4,000 ft altitude, the air is approximately 90% as dense as at sea level. Engine emissions generally are related to the pertinent fuel/air (f/a) ratio. While the fuel rate remains constant, increasing the altitude would correspondingly decrease the air weight flow and thus make the f/a mixture fuel-rich. This would increase the toxicity of the emissions, invalidating the assessed ventilation rate.

Thus, to maintain the f/a ratio and the validity of the ventilation rate, the fuel rate must be commensurately reduced, or the ventilation rate increased. As the former is usually more easily accomplished, the fuel rate is usually reduced.

Table 4 is derived from an equation found in (8). The relative density factor is the same as the fuel rate reduction factor. The table provides an approximate idea of the possible variations.

Table 4 - Variation of Ventilation Factor with Altitude

altitude (ft)	fuel reduction factor	ventilation increase factor
- 6000	1.20	0.83
- 4000	1.13	0.89
- 2000	1.06	0.94
sea level	1.00	1.00
+ 2000	0.94	1.06
+ 4000	0.89	1.13

Consequently, it has long been the practice to reduce the fuel rate for increasing altitude. For an altitude of 4,000 ft in the Rocky Mountain Region, the fuel rate would decrease to 89% of the sea level value, or the ventilation would increase by 13%. Conversely, at a depth of 6,000 ft, the fuel rate could be increased by 20% or the ventilation reduced by 17% to maintain the same air quality.

Ventilation Distribution Efficiency

CANMET has, for a number of years, been gathering data on the efficiency with which available ventilation air is channeled to the locations (typically dead-end headings ventilated with auxilliary ducts) in which vehicle operators function. The data provides an indication of the operator exposure relative to the levels of pollutants in the return air from the area considered. This data is presented in Table 5.

Table 5 - Summary of Operator Exposure Data from Underground Environment Investigations in Seven Canadian Mines

mine /run #/#	ref.	equipment description		CO_2 (ppm) and RCD (mg/m^3) concentrations: in air	ret air	LHD	trck #1	trck #2	ventil-ation (cfm)	operat-or expo sure (%)
1/1	1	LHD/Deutz/ catalyst	CO_2	840	1010	1540	-	-	34,000	180
			RCD	0.06	0.72	1.07	-	-		149
1/2	1	LHD/Deutz/ filter	CO_2	640	1020	1260	-	-	36,000	136
			RCD	0.05	0.36	0.64	-	-		178
2/1	1	LHD/Deutz/ catalyst	CO_2	1020	1940	1740	-	-	25,000	87
			RCD	0.27	1.06	0.61	-	-		58
2/2	1	LHD/Deutz/ filter	CO_2	790	1870	1640	-	-	25,000	85
			RCD	0.24	0.45	0.50	-	-		111
3/1	1	LHD/Deutz/ catalyst	CO_2	420	570	790	-	-	33,000	200
			RCD	0.32	0.93	0.86	-	-		92
3/2	1	LHD/Deutz/ filter	CO_2	440	680	980	-	-	28,000	191
			RCD	0.43	0.50	0.46	-	-		90
4/1	2	LHD/Deutz/ catalyst	CO_2	1279	1643	2620	-	-	90,000	176LHD
							1950	-		124TR1
							-	2090		135TR2
4/2	3	LHD/Deutz/ catalyst	CO_2	556	689	1075	-	-	91,000	210
			RCD	0.14	0.22	0.44	-	-		200
4/3	3	LHD/Deutz/ catalyst	CO_2	593	688	619	-	-	70,000	80LHD
							886	-		higherTR1
4/4	3	LHD/Deutz/ catalyst	CO_2	720	860	817	-	-	32,000	92LHD
			RCD	0.34	0.60	0.56	-	-		93
5/1	4	LHD/Deutz/ catalyst	CO_2	-	1809	1390	-	-	17,000	71LHD
							2000	-		113TR1
6/1	5	Loader/ Cat 3306 catalyst	CO_2	460	950	1120	-	-	107,000	128LDR
							1030	-		113TR1
6/2	5	Loader/ Cat 3306/ catalyst	CO_2	420	920	1310	-	-	79,000	168LDR
							840	-		86TR1
7/1	6	LHD/Deutz/ catalyst	CO_2	-	1760	2400*	-	-	32,000	145LHD
							1900	-		110TR1

*minimum as maximum scale reading was surpassed

Examination of the data indicates:

(1) that LHD operators who enter dead-end headings are subjected to 70 to 200% of the general mine air return concentrations of the pollutants,

(2) that haulage truck drivers are exposed to lesser concentrations than LHD operators, but to a none-the-less significant 86 to 135% of the pollutants in the general mine return air, and

(3) that RCD levels to which LHD operators are exposed in Canadian mines range from 0.44 to 1.07 mg/m^3, and greater. Values as high as 3.14 mg/m^3 in the general mine air have been measured, but the corresponding LHD operator value was not measured.

It is likely that the use of exhaust diluters would improve the efficiency of utilization of the available ventilation. Unfortunately, there does not appear to be published information regarding its performance (even though the experiments are simple to do).

The above analysis puts numbers on the importance of systematically moving the vent tubing toward the work area face. These numbers have been incorporated into the Appendix III Clause revision table.

Machine Loading Cycle

CANMET and others have made several efforts to document the loading of underground production machines. The result of this work was incorporated into the coal mine diesel standard CSA M424.1 (1). The note on p. 22 of that Standard says: "Machine load factor studies have been reported (1983) in Canada, Sweden and the USA. A maximum load factor of 0.85 relative to full load, full speed operation is reported for a heavily-loaded Load-Haul-Dump machine. Some haulage trucks exhibit a load factor of 0.70, whereas utility machines and personnel carriers may operate at a 0.50 level load factor. These rules of thumb should be used...by the appropriate Regulatory Authority to reduce ventilation rates (see Clause 5.8) according to machine type, assuming individual concentrations of toxic constituents remain below their respective current TLVs..."

These upper limits, along with estimated lower limits, are found in Table 3 of Clause 5.5 of Appendix IV.

Multiple Machine Density

This factor will vary for every level of every mine. An unpublished survey of a heavily dieselized mine employing numerous machines, indicated that only 30% of installed production machine horsepower was utilized on average over a number of shifts. This is estimated from use of the net increase in CO_2 due to diesel emissions in the following equations, derived from first principles in (9):

$$\text{operating horse power} = \frac{\text{ventilation in cfm X (net } \%CO_2)}{\text{46.1 X brake specific fuel consumption}}$$

$$\text{overall mine vehicle load factor} = \frac{\text{operating hp}}{\text{installed hp}}$$

Further, in other confidential studies, one 26% and two 42% load factors were measured. Evidently, the load factor for multiple machine operation is considerably less than 1.0 in practice. However, the maximum would be 0.85 for a single LHD. Therefore, the applicable range would appear to be 0.25 to 0.85 as given in Table 3 of recommended Clause 5.5 in Appendix IV.

Mine Layout

Mine Layout can affect the degree of pollution impact in a number of ways. If inadvertent recirculation or leakage across a brattice cloth barrier occurs for example, then ventilation effectiveness is reduced. How much can only be determined by measurement.

High headings tend to allow the hot pollutants to rise by convection to the top of a high dead-end heading. Emission of the exhaust to the back (by the use of a "hockeystick" shaped exhaust pipe), then reduces the exposure of the machine operator by an estimated 10%. High cavernous headings (such as encountered in salt and potash mines) with sluggish air flow, permit the accumulation of high NO and NO_2 concentrations, and permit the conversion of significant amounts of NO to NO_2 resulting in a negative impact on the quality of the environment downstream.

In general, these effects can only be determined by on-site measurements, so that no attempt is made here to estimate the ventilation factors involved for inclusion in Appendix IV.

Efficacy of Maintenance

A comprehensive, landmark investigation was undertaken by R. Waytulonis (10) who studied the effects of maintenance, maladjustments, and errors on the emissions of diesel engines underground.

Some effects were dramatic. However, in most circumstances, such emissions changes are intolerable and some maintenance action is undertaken to correct the problem. Further, deterioration of the engine with operating time may not mean a serious increase in pollutants in the overall toxicity sense. For example ring wear would reduce compression with time. This would, in turn, likely reduce NO and increase CO and soot in partially compensating changes. Such effects, however, are to be avoided by a serious maintenance program. Use of catalysts to help control increases in CO and filters to limit increase in soot, can help to reduce the impact of lack of timely maintenance. No attempt is made here to suggest ventilatiion factors associated with this item.

Use of Low-Sulphur Fuel

CSA Standards M424.1 and .2 (1), require emissions testing to be performed employing diesel fuel as specified in the CGSB Mining Fuel Standard (12). This standard permits the use of diesel oil at the mine site which contains a maximum of 0.5% sulphur by weight. However, some mining operations purchase premium fuel with a normal analysis of less than 0.1% sulphur. Fuels from tar sand-derived Western crudes have typical sulphur analyses of less than 0.1%. In general, the calculations of performance in this document have been based on a mid-range value of fuel sulphur of 0.2%.

The EQI expression rewards the use of lower sulphur fuels by proportional reductions in ventilation. The fuel sulphur calculations of Appendix II indicate that, for the F6L 714 engine considered, the ventilation prescribed by the EQI reduces from a maximum of 27,514 scfm for an S = 0.5%, to 21,192 scfm for the mid-range S = 0.2%, to 19,077 scfm for S = 0.1%, to 11,234 scfm for zero sulphur in the fuel.

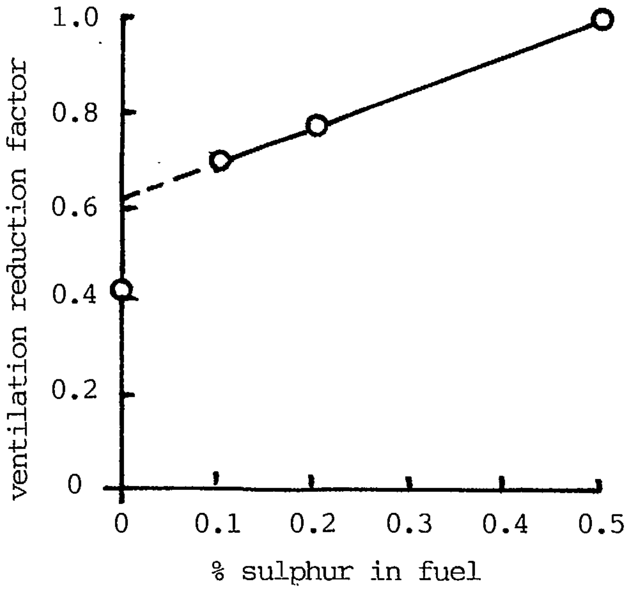

Fig. 1 - Effect of Fuel Sulphur on Ventilation Reduction Factor

Table 6 - Ventilation Reduction Factors for varying Fuel Sulphur Content

sulphur in fuel (% by wt)	Deutz F6L714 ventilation (scfm)	Vent reduction factor
0.0	11,234	0.41
0.1	19,077	0.69
0.2	21,192	0.77
0.5	27,514	1.00

Therefore the range for the ventilation reduction factor due to reduced fuel sulphur would be 0.69 to 1.00 for a usual sulphur range of 0.1% to 0.5% respectively. This range is included in the ventilation reduction factors of Table 3 of suggested Clause 5.5 in Appendix IV.

For desulphurized tar sand fuel, for which the fuel sulphur approaches zero, the entire SO_2 term in the EQI expression would disappear, and the ventilation could then be reduced to 41% of the 0.5% sulphur fuel value.

CONCLUSION

Ventilation prescribed according to CSA Standards M424.1 and .2, is designed to be universally applicable all across Canada. Therefore, the ventilation assessment is provided for the worst case, i.e. a single machine operating at its most polluting conditions, using 0.5% sulphur fuel.

There are, however, a number of on-site, in-mine factors which relate directly to the ventilation need underground. Unfortunately, these cannot be foreseen at the certification stage.

To provide an example of the combined ventilation change such factors might suggest, possible on-site ventilation reduction factors have been assumed for an LHD operator in Table 7 below.

Table 7 - Combined Ventilation Reduction Factor

	factor	assumed value
1	altitude (just below sea level)	0.90
2	ventilation distribution efficiency	1.30
3	individual vehicle load factor	(0.60)*1
4	multiple machine density	0.50
5	mine layout - recirculation (none)	1.00
	- leakage by-pass (a little)	1.05
	- high headings (none)	1.00
6	efficacy of maintenance	1.10
7	fuel sulphur	0.70
	combined factor	0.47

*1 included in multiple machine density factor

The combined ventilation reduction factor would become 0.47, and the ventilation relative to the maximum value of 27,514 scfm (for an LHD with untreated exhaust utilizing fuel of 0.5% sulphur) would be 0.47 X 27,514 = 12,931 scfm, and the brake specific ventilation would be 97.2 cfm/bhp for these specific conditions.

REFERENCES

(1) CSA Standards M424.1 (coal) and .2 (non-coal). The latter is entitled "Non-rail-bound diesel-powered machines for use in non-gassy underground mines." The Standard is in the ballotting process at time of writing.

(2) Dainty, E.D. - "Comparison of ventilation prescription criteria for certification of diesel engine-equipped mining machinery." CANMET report MRL 89-101 (OP).

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APPENDIX I - COMPARISON OF DEUTZ AND DDAD ENGINE EMISSIONS

During various past R/D programs, CANMET/MRL/CEAL, the Ontario Ministry of Labour, and the United States Bureau of Mines, have issued contracts to ORTECH (formerly ORF), to undertake emissions evaluations of these two engines in order to compare the various points of interest. The emissions results of three CANMET contracts are recorded in the following table.

Comparison of Deutz and DDAD*1 Untreated Engine Emissions

item	units	Deutz (4-stroke) indirect injection F6L 714		DDAD (2-stroke) direct injection 8V71N		
load	%	100		100	75	50
speed	%	100		100	100	100
injectors		std		B5	B5	B5
injection		24 deg BTDC		1.5 in	1.5 in	1.5 in
speed	rpm	2200	2200	2150	2150	2150
torque	lb.ft	300	318	540	405	270
power	bhp	126	133	221	166	110
air flow	lb/hr	1298	1320	3663	3776	3663
fuel flow	lb/hr	60.9	60.7	89.7	70.8	52.2
water	lb/hr	76.7	77.0	113.0	89.2	65.7
wet gas	lb/hr	1359	1381	3753	3847	3715
dry gas	lb/hr	1282	1304	3640	3758	3649
f/a ratio	-	0.0469	0.0460	0.0245	0.0188	0.0143
exh. temp.	deg F	1009	-	671	583	477
BSFC	lb/bhp.hr	0.480	0.456	0.406	0.427	0.475
CO2	%	10.3	10.0	5.2	4.0	3.0
CO	ppm	114	147	180	70	60
NO	ppm	510	552	1190	800	440
NO2	ppm	trace	trace	60	30	40
SO2 *3	ppm	-	87.2	46	-	-
soot	mg/m3	58.4	59.5	25.0*2	22.3	21.7
	g/kw.hr	0.30	0.30	0.21	0.18	0.27
	g/bhp.hr	0.22	0.22	0.16	0.13	0.20
EQI	-		183*4	145*4	-	-
ventiltn	cfm		17,700	39,100		
	cfm/bhp		133	177		
source	-	ORF	ORF		ORF	
		Mar 30/79	7-9097		-	
		#2722/02	#3503		#2512/5	

*1 DDAD - Detroit Diesel Allison Division *2 extrapolated value
*3 0.2% sulphur in fuel #4 note EQI soot limit used is 2.0 mg/m^3

APPENDIX II - CALCULATIONS

Using the performance attributes of Tables 1 and 2, the overall EQIs and ventilation recommendations pertinent to the several treatment options, are:

Bare Engine

$$EQIgas = \frac{CO}{50} + \frac{NO}{25} + \frac{NO_2}{3.0} = \frac{147}{50} + \frac{552}{25} + \frac{10}{3} = 2.94 + 22.08 + 3.33$$

$$= 28.4$$

$$EQIsoot = \frac{soot}{1.5} + \left[\frac{SO_2}{3.0} + \frac{soot}{1.5}\right] + \left[\frac{NO_2}{3.0} + \frac{soot}{1.5}\right] = \frac{87.2}{3.0} + \frac{10}{3.0} + \frac{3 \ X \ 59.5}{1.5}$$

$$= 29.1 + 3.3 + 119.0 = 151.4 \text{ and,}$$

$$\text{Dilution Ratio} = 151.4/2.0 = 75.7$$

Note that the soot expression is equated to 2.0 as IW French and Associates prescribed. However, the soot "TLV" of 1.5 is used in the individual terms of the EQI expressions rather than the RCD "TLV" of 2.0, because the additional matter contained in the RCD measured underground (drill oil mist, evapourated lubeoil and fuel, etc.) which increases the "TLV" to 2.0, is not present in the lab tests. Note that the fraction of the additional matter in the RCD relative to soot is assumed to be (2.0 - 1.5)/1.5 = 0.33, and that the ratios (59.5X 1.33)/2.0 for RCD, and 59.5/1.5 for soot are identical, i.e. 39.7. Therefore,

$$EQI_{overall} = \frac{147}{50} + \frac{552}{25} + \frac{59.5}{1.5} + 1.5\left[\frac{87.2}{3.0} + \frac{59.5}{1.5}\right] + 1.2\left[\frac{10}{3.0} + \frac{59.5}{1.5}\right]$$

$$= 2.9 + 22.1 + 39.7 + 103.1 + 51.6 = 219.4, \text{ and}$$

$$\text{Dilution Ratio} = 219.4/3.0 = 73.1$$

Note that the gas only dilution ratio is very small relative to either of the overall or the soot criteria, which are virtually identical. This was noted in 1981 by IW French in Table 151, p. 559 of (11). Consequently, CANMET/MRL/CEAL has continued to use the overall relationship, as it has the advantage of being single and comprehensive, and ultimately more computer-compatible for future potential developments in ventilation control. Therefore,

$$\text{Ventilation engine recommended} = \frac{1304 \ X \ 219.4/3.0}{3600 \ X \ 0.075} = 353 \text{ cfs} = 21{,}192 \text{ cfm, and}$$

Brake Specific Ventilation (BSV) = 21,192/133 = 159.3

Catalytic Purifier

$$EQI_{overall} = \frac{30}{50} + \frac{552}{25} + \frac{59.5}{1.5} + \frac{76.2}{1.0} + 1.5\left[\frac{69.8}{3.0} + \frac{59.5}{1.5}\right] + 1.2\left[\frac{10}{3.0} + \frac{59.5}{1.5}\right]$$

= 0.6 + 22.1 + 39.7 + 76.2 + 94.4 + 51.6 = 284.6, and the

$$\text{Ventilation}_{\text{calculated}}\ \text{catalyst} = \frac{1304 \times 284.6/3.0}{3600 \times 0.075} = 458 \text{ cfs} = 27{,}490 \text{ cfm}$$

or, if the H_2SO_4 disappears from the environment so that no exposure to it occurs (as measurements tend to suggest), then the H_2SO_4 term disappears from the EQI expression and the new EQI value would be 284.6 - 76.2 = 208.4, and the recommended ventilation rate would become 20,130 cfm, a figure slightly less than the bare engine value. The brake specific ventilation becomes 27,490/133 = 207 cfm/bhp.

Ceramic Filter

$$EQI_{filter} = \frac{1.1 \times 147}{50} + \frac{552}{25} + \frac{6.0}{1.5} + 1.5\left[\frac{87.2}{3.0} + \frac{6.0}{1.5}\right] + 1.2\left[\frac{10}{3.0} + \frac{6.0}{1.5}\right]$$

= 3.2 + 22.1 + 4.0 + 49.6 + 8.8 = 87.7, & the corresponding

$$\text{calculated ventilation filter} = \frac{1304 \times 87.7/3.0}{3600 \times 0.075} = 141.2 \text{ cfs} = 8{,}471 \text{ cfm}$$

Using the 50% benefit recommendation, the ventilation for the ceramic filter becomes:

recommended ventilation = 0.5(21,192 - 8,471) + 8,471
= 14,832 cfm

& cfm/bhp = 14,832/133 = 112 cfm/bhp

Water Scrubbers

From the data of Table 2, the following performance assumptions were made:

(1) baffle scrubbers: soot removal efficiency....30%
SO_2 removal efficiency.....70%
NO_2 removal efficiency......0%

(2) venturi scrubber: soot removal efficiency....70%
SO_2 removal efficiency.....30%
NO_2 removal efficiency......0%

Using these performance attributes, the overall EQIs are:

$$EQI_{baffle} = \frac{147}{50} + \frac{552}{25} + \frac{0.7 \times 59.5}{1.5} + 1.5\left[\frac{0.3 \times 87.2}{3.0} + 27.7\right] + 1.2\left[\frac{10.0}{3.0} + 27.7\right]$$

$$= 2.9 + 22.1 + 27.7 + 54.6 + 37.2 = 144.5$$

$$EQI_{venturi} = \frac{147}{50} + \frac{552}{25} + \frac{0.3 \times 59.5}{1.5} + 1.5\left[\frac{0.7 \times 87.2}{3.0} + 11.9\right] + 1.2\left[\frac{10.0}{3.0} + 11.9\right]$$

$$= 2.9 + 22.1 + 11.9 + 48.4 + 18.2 = 103.5$$

Using the 50% benefit recommendation, the ventilation for the two scrubbers is calculated as follows:

$$\text{calculated ventilation baffle} = \frac{1304 \times 144.5/3.0}{3600 \times 0.075} = 232.6 \text{ cfs} = 13{,}958 \text{ cfm}$$

recommended = 0.5(21,192 - 13,958) + 13,958 = 17,575 cfm

& cfm/bhp = 132.1 cfm/bhp, and

$$\text{calculated ventilation venturi} = \frac{1304 \times 103.5/3}{3600 \times 0.075} = 166.6 \text{ cfs} = 9{,}997 \text{ cfm}$$

recommended = 0.5(21,192 - 9,997) + 9,997 = 15,595 cfm

& cfm/bhp = 117.3 cfm/bhp

Fuel Sulphur Effects

The maximum fuel sulphur according to (12) is 0.5% by weight. The SO_2 concentration in the untreated exhaust then becomes 0.5/0.2 X 87.2 = 218 ppm. Therefore, the bare engine EQI for this value is:

$$EQI_{(0.5\%)} = \frac{147}{50} + \frac{552}{25} + \frac{59.5}{1.5} + 1.5\left[\frac{218}{3.0} + \frac{59.5}{1.5}\right] + 1.2\left[\frac{10}{3.0} + \frac{59.5}{1.5}\right]$$

$$= 2.9 + 22.1 + 39.7 + 168.5 + 51.6 = 284.8$$

and the corresponding ventilation requirement for 0.5% sulphur fuel would be:

$$\underset{(0.5\%\ S)}{\text{ventilation}} = \frac{1304 \times 284.8/3.0}{3600 \times 0.075} = 459 \text{ cfs} = 27{,}514 \text{ scfm}$$

similarly, for 0.1%S fuel,

the EQI = 197.5, and the
ventilation = 19,077 scfm, and

similarly, for 0.0%S fuel,

the EQI = 116.3, and the
ventilation = 11,234 scfm.

APPENDIX III - SUGGESTED ADDITIONS TO CLAUSE 5.4

5.4 Assessed Ventilation Recommendations

The results of tests at the engine operating conditions which produce the greatest toxicity hazard, and as specified in Clauses 4.5.4 and 5.3, shall be employed in the following equation to assess the ventilation recommendation for untreated exhaust and for the exhaust leaving the last exhaust treatment device prior to exhaust dilution and emission into the environment:

$$Q_{dva} = \frac{M_{dxg} \times \frac{EQI}{3.0} + \left[\frac{9H_2\%}{100} - 1\right] M_f}{3600 \times \rho} \quad m^3/s$$

where: Q_{dva} = the flow rate of dry ventilating air for the diesel machine in m^3/s.

EQI = the Exhaust Quality Index defined by Clause 4.5.4.1

M_{dxg} = the dry exhaust gas rate produced by combustion of the fuel in kg/h

M_f = the fuel consumption rate in kg/h

ρ = the dry ventilation air density in kg/m^3

H_2 = the percent by weight of hydrogen in the fuel

Note: In order to provide comparisons of the emissions reduction performance of exhaust treatment devices, as well as their potential impact on the magnitude of the recommended ventilation, Table 2 has been prepared. As treatment device performance varies considerably, these ventilation factors should be regarded as guides only.

Table 2

Example Exhaust Treatment Device Ventilation Reduction Factors

	option	vent factor
1	untreated engine exhaust	1.00
2	catalytic purifier	1.00
3	conventional water scrubber	0.85
4	venturi water scrubber	0.75
5	ceramic filter	0.70

APPENDIX IV - RECOMMENDED ADDITION OF CLAUSE 5.5

5.5 In-Mine Factors Modifying Recommended Ventilation

The level of ventilation recommended in Clause 5.4 will apply to all applications of the power pack so tested. That recommended ventilation rate pertains to the worst engine operating conditions from an emissions toxicity point of view, and therefore represents a maximum. There are several on-site, in-mine conditions which may indicate changes to this maximum ventilation level. These conditions are listed in Table 3, along with examples of the magnitude of the ventilation-altering factor as a guide only.

Table 3

On-Site Ventilation Altering Factors

	condition		vent factor
1	altitude (-6,000 ft to +4,000 ft)		0.83 to 1.13
2	ventilation distribution efficiency:		
		LHD	0.70 to 2.00
		haulage truck	0.86 to 1.35
3	machine loading cycle:	LHD	0.65 to 0.85
		haulage truck	0.50 to 0.70
		others	0.50 or less
4	multiple machine density		0.25 to 0.85
5	mine layout:	recirculation	-
		leakage by-pass	-
		high headings	-
6	efficacy of maintenance		-
7	fuel sulphur concentration		0.69 to 1.00