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MAnufacturer's **P**ro**T**ocol
for
Exhaust **S**ystems **T**esting
(**MAPTEST**)

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authored by: members of the Diesel Exhaust Evaluation PROtocol Committee (DEEPROC)

prepared for: segments of the North American Mining Industry utilizing diesel exhaust treatment systems

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NATURAL RESOURCES CANADA
CANADA CENTRE FOR MINING AND MINERALS TECHNOLOGY (OTTAWA)
MINING AND MINERAL SCIENCES LABORATORIES
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MANUFACTURERS' PROTOCOL FOR EXHAUST SYSTEMS TESTING (MAPTEST)

INTRODUCTION:

This MAPTEST protocol has been developed by DEEPROC by a process of iterative consultations, which included representatives of manufacturers of emission control systems, interested consultants, and the convening Secretariat - the Mining and Mineral Sciences Laboratories (MMSL), of the Canada Centre for Mineral and Energy Technology (CANMET), of Natural Resources Canada (NRCAN), in Ottawa.

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PROTOCOL OBJECTIVE:

To define for the mining industry, by dynamometer testing, the emissions performance (and other pertinent parameters) of addon systems including: fuel variations, additives, catalytic converters, filters, and other treatment technologies, applied either singly or in combination, to mining diesel engines.

DEEPROC POSITION REGARDING SYSTEM EVALUATION CRITERIA:

1) Any reduction in the concentration of a diesel exhaust pollutant is deemed by DEEPROC to be beneficial.

2) Irrespective of variations in individual pollutants, an overall reduction in the value of the Exhaust Quality Index (EQI), is deemed beneficial (see EQI background description in Appendix I; & definition on p. 5).

3) In applications where the engine is 'certified', the addon system performance should not cause an increase in the concentration of any individual pollutant above that specified in the pertinent certification standard.

TEST PROCEDURE DESCRIPTION:

The engine emissions are to be determined initially with no treatment system or device installed in order to establish the baseline engine emissions. Subsequent tests will then determine the performance of the treatment technology to be tested.

1) Mining Test Engine Required:

The emissions tests are to be performed using a typical mining diesel engine.

2) Test Fuel Specifications:

Both the baseline engine emissions tests, and the tests on the treatment system(s), will be performed using the same fuel 'lot'. The fuel will conform to the `special fuel' specification described in CGSB standard, CAN.CGSB 2-3.16 - 'Mining Diesel Fuel'. However, the fuel sulphur content will not exceed 0.05% by weight for these tests. Fuel requirement(s), in addition to those specified in this Mining Diesel Fuel Standard, are to be reported in Appendix IV.
Other fuels than the "Mining Diesel Fuel" specified (CAN.CGSB 2- 3.16), may be employed for these tests providing that the fuel properties are adequately

documented. For convenience, a comprehensive list of standard methods for fuel analysis tests are provided in Appendix II. An analysis of the fuel 'lot' to be used, will determine the carbon, hydrogen, and sulphur contents, the specific gravity, and the cetane index of the fuel, all as reported in Appendix IV.

3) Specification of Engine Operating Test Conditions:

Both the baseline and the treatment system tests will be conducted under the steady-state load conditions specified in ISO/DIS 8178-4.2, for the 8-mode, type C1 equipment - "Off-road vehicles, diesel-powered off-road industrial equipment," as in Table 1 below.

Under normal rated operating conditions, with normal intake or exhaust devices (such as intake air filter and exhaust muffler), installed on the engine, the intake air restriction and the exhaust back pressure are typically well within the limit values recommended by the engine manufacturer. Accordingly, the technology to be tested is to exhibit intake and exhaust pressure loss characteristics such that the engine manufacturer's recommendations are not exceeded with the technology installed and operated at the conditions of mode 1 of Table 1.

Table 1 - **Engine Operating Conditions (8-Mode Schedule)**

Mode	Speed *1	% Load *2	Weighting factor *3
1	rated	100	0.15
2	rated	75	0.15
3	rated	50	0.15
4	Rated	10	0.10
5	intermediate	100	0.10
6	intermediate	75	0.10
7	intermediate	50	0.10
8	low idle	0	0.15

NOTES APPLICABLE TO TABLE 1:

*1 Rated speed is the speed at which the manufacturer specifies the rated power of the engine; intermediate speed is the peak torque speed, when the peak torque speed is between 75% and 60% of the rated speed, otherwise it is 60% or 75% of the rated speed, whichever is closer to the peak torque speed.

*2 Percent (%) load is the fraction of the maximum available torque at that engine speed.

*3 These weight factors will be used to calculate integrated emission values, the integrated EQI, and the %ESE as defined below (see page 6).

Further, for both baseline engine and addon system tests at mode 1 of Table 1, the test back pressure and intake vacuum (for a clean air filter) shall be deliberately adjusted to those maximum values permitted by the engine manufacturer. That adjustment shall be fixed, and shall thereafter remain in place for all tests at other operating conditions.

After the testing of a treatment system, the engine baseline tests will be repeated to gauge the changes in the testing parameters. Such changes will be recorded in Appendix III.

All the essential measurements (torque, engine speed, fuel flow, air flow, temperatures, pressures, emissions, etc. - see the example data sheet of Appendix III), will be recorded for each test point. All such test measurements may conform to the requirements of ISO/DIS 8178-1.2.

The add-on system performance will be determined, after an 'aging period' recommended by the add-on system manufacturer, on an engine already 'broken in' in accordance with the engine manufacturer’s requirements.

4) Exhaust Gas Components to be Measured:

For each test, the exhaust gas components measured, using the instrumentation principle corresponding, will include those listed in Table 2, below. The listed measurements included in the results sheet of Appendix III, will be corrected to dry, standard conditions for reporting purposes.

Table 2 - **Exhaust Gas Components to be Measured**

component measurement	measured principle
O_2	paramagnetic
CO	infra-red
CO_2	infra-red
NO	chemiluminescent or FTIR (Fourier Transform)
NO_2	chemiluminescent or FTIR (Fourier Transform)
SO_2	infra-red or ultra-violet
THC	heated flame ionization detection
diesel particulate matter (DPM)	gravimetric analysis

CALCULATION OF EMISSIONS SYSTEM EFFECTIVENESS (ESE):

Step 1:
For each set of engine operating conditions, the comprehensive emissions quality will be calculated using the Exhaust Quality Index (EQI) criterion in order to provide a universally applicable basis for performance assessment of engine and exhaust treatment systems. It should be noted that higher values of the Index correspond to lower values of emissions quality.

The EQI equation is defined as follows:

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

where the gases are in units of ppm and DPM in mg/m^3 of dry exhaust gas.

Step 2:

The integrated Exhaust Quality Index for all the operating conditions (see specification of 8-mode operating conditions in Table 1, above) will be determined as follows:

$$EQI_{integrated\ 1\text{-}8} = \Sigma [\, EQI_{x}\, x8 \text{ - } mode weight\ ing\ \ factor_{x}\,]_{1\text{-}8}$$

Step 3:

The Emissions System Effectiveness (ESE), is then calculated using the integrated values of the EQI, as follows:

$$\%ESE = \frac{EQI_{baseline} - EQI_{addon}}{EQI_{baseline}} x100$$

TEST REPORTING:

A report describing the testing of the emissions reduction system will be produced. The test data and report are to be kept on file for a period of five (5) years. The report will include:

1) engine and other equipment specifications (see Appendix IV for example)

2) fuel specification variations from the CGSB Mining Fuel Standard, and analyses (see Appendix IV)

3) a brochure describing the emissions reduction system (optional)

4) a description of geometry of emissions system to be tested; for example, for a ceramic filter:

   overall length X outside diameter X substrate volume

5) test data recorded in Appendix III, including the part number relating uniquely to the catalyst, additive, etc. (an aftertreatment catalyst specification, for example, must be such as to permit the matching of the test results with the system tested)

6) a calculation and recording of the integrated EQIs and ESE

PUBLICATION OF TEST DATA:

The data recorded during the testing program will be confidential to the emissions technology manufacturer, and will be released to the mining industry and the general public in the form of reports and papers, for example, only after receiving the manufacturer's permission.

ADDITIONAL ANALYSES:

Some analyses in addition to those above may prove useful. Such additional tests potentially include: polynuclear aromatic hydrocarbons (PNAs) analysis, analysis of aldehydes, opacity testing, DPM size distribution analysis, chemical DPM analysis (including SOF, sulphates and elemental carbon), and Ames mutagenic testing.

A MATTER FOR FUTURE CONSIDERATION:

This document will be reviewed by DEEPROC every two years in order to incorporate desirable changes to the procedures and add any new requirements deemed beneficial. One such consideration to be explored is that of defining durability performance testing.

DISCLAIMER:

Her Majesty the Queen in right of Canada, represented by the Minister of Natural Resources ("Canada"), and other members participating in the Diesel Exhaust Evaluation Protocol Committee ("DEEPROC") make no representations about the suitability for any purpose of the information contained in this Manufacturer's Protocol for Exhaust Systems Testing document ("MAPTEST"). MAPTEST is provided on an "as is" basis and Canada and the other members of DEEPROC make no representations or warranties respecting MAPTEST, either expressed or implied, arising by law or otherwise, including but not limited to, effectiveness, completeness, accuracy or fitness for a particular purpose. Canada and the other members of DEEPROC do not assume any liability in respect of any damage or loss incurred as a result of the use of MAPTEST. In no event shall Canada or any other member of DEEPROC be liable in any way for the loss of revenue or contracts, or any other consequential loss of any kind resulting from the use of MAPTEST.

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APPENDIX I NOTES REGARDING THE BENEFITS OF THE USE OF THE AIR (AQI) & EXHAUST (EQI) QUALITY INDICES

(1) The CANMET/USBM/MOL(Ontario) Collaborative Diesel Research Advisory Panel (CDRAP - 1978-1986) program, which developed and validated the ceramic filter among other important matters, chose the AQI/EQI expression as the sole means by which emissions constituent reduction developments were to be assessed.

(2) It is specified in National Canadian Standards CSA M424.1 (1989) for coal mine diesels, and CSA M424.2 (1990) for non-coal mine diesels, as the sole criterion by which to assess emissions quality and calculate the ventilation requirements for certified mining machinery. Several Canadian Provinces have incorporated this criterion into legislation (or are about to do so), for ventilation calculation and prescription.

(3) Use of the comprehensive AQI/EQI expression as the ventilation prescription criterion is intrinsically advantageous because it accounts for the multiple changes in emissions generated by engine adjustments and the application of exhaust treatment technologies.

(4) Engines vary threefold in brake specific ventilation (cfm/bhp.hr). The 100 cfm/bhp rule- of-thumb, when applied, does not give a manufacturer credit for producing a less polluting engine, nor an effective exhaust treatment system. Use of a ceramic filter, for example, reduces the EQI, and therefore the corresponding ventilation requirement, by a factor of approximately 50%, due solely to substantial DPM removal.

(5) The purchase of low sulphur fuel likewise receives no credit from the 100 cfm/bhp rule of thumb. In contrast, use of the EQI criterion results in, for example, a 59% reduction by using low (zero in this case) fuel sulphur, compared to zero reduction for the maximum of 0.5 % fuel sulphur permitted in the CGSB Mining Fuel Standard referred to in the above-mentioned CSA standards.

(6) Engines tested at the worst operating condition (often full load/speed), and evaluated using the AQI/EQI, frequently require greater ventilation than the 100 cfm/bhp criterion prescribes. However, factors in the field beyond the control of the certifying agency, such as machine duty cycle and exhaust treatment factors, can reduce the precribed maximum ventilation value to considerably lesser values to maintain air quality.

(7) Field measurements have shown that there is a linear relationship between the AQI and the %CO2 in the ambient mine environment. Many Canadian mines are now interested in mine environment monitoring, and ultimate partial or complete ventilation control to effect savings. CO2 monitoring is simple, inexpensive and reliable. The AQI, as the backup quality criterion, is most useful in such circumstances. This relationship is also useful in the monitoring of LHD operator exposure, as underground measurements have shown that such exposure varies from 0.70 to 2.00 times the pollutant concentrations that are measured in the mine return air from the immediate area of machine operation.

(8) Most recently, the criterion has been employed during the construction phase of the underground CHUNNEL project joining Britain with France.

APPENDIX II **FUEL TEST METHOD STANDARDS FROM CAN/CGSB-3.16**

APPLICABLE ASTM PUBLICATION (par. 2.1.2)
Annual Books of ASTM Standards

D 86	Standard Test Method for Distillation of Petroleum Products
D 93	Standard Test Method for Flash Point by Pensky-Martens Closed Tester
D 130	Standard Test Method for Detection of Copper Corrosion from Petroleum Products by the Copper Strip Tarnish Test
D 445	Standard Test Method for Kinematic Viscosity of Transparent and Opaque Liquids (and the Calculation of Dynamic Viscosity)
D 482	Standard Test Method for Ash from Petroleum Products
D 524	Standard Test Method for Ramsbottorn Carbon Residue of Petroleum Product
D 613	Standard Test Method for Ignition Quality of Diesel Fuels by ft Cetarie Method
D 974	Standard Test Method for Neutralization Number by Color-Indicator Titration
D 976	Standard Test Methods for Calculated Cetane Index of Distillate Fuel
D 1266	Standard Test Method for Sulfur in Petroleum Products (Lamp Method)
D 1298	Standard Test Method for Density, Relative Density (Specific Gravity). or AP Gravity of Crude Petroleum and Liquid Petroleum Products by Hydrometer Method
D 1552	Standard Test Method for Sulfur in Petroleum Products (High-Tempcrature Method)
D 1796	Standard Test Method for Determination of Waie. and Sediment in Fuel Oils by the Centrifuge Method (Laboratory Procedure)
D 2273	Standard Test Method for Trace Sediment in Lubricating Oils
D 2500	Standard Test Method for Cloud Point of Petroleum Oils
D 2622	Standard Test Method for Sulfur in Petroleum product by X-Ray Spectrometry
D 2624	Standard Test Method for Electrical Conductivity of Aviation arid Distillate Fuels Containing a Static Dissipator Additive
D 3117	Standard Test method for Wax appearance Point of Distillate Fuels
D 3328	Standard Test Method for Flash Point by Setaflash Closed Tester
D 4052	Standard Test Method of Density and Relative Density of Liquids by Digital Density Meter
D 4057	Standard Practice for Manual Sampling of Petroleum and Petroleum Products
D 4294	Standard Test Method for Sulfur in Petroleum Products by Energy-Dispersive X-Ray Fluorescence Spectrometry
D 4530	Standard Test Method for Determination of Carbon Residue (Micro Method)
D 4737	Test Method for Calculated Cetane Index by Four Variable Equation
D 4865	Guide for the Generation and Dissipation of Static Electricity in Petroleum Fuel Systems
E 29	Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications.

APPENDIX IIIA **FINAL EXHAUST TREATMENT TECHNOLOGY TEST RESULTS (METRIC EXAMPLE)**

Date:
engine manufacturer: exhaust treatment system manufacturer :
engine model # : exhaust treatment system part # :
engine serial # : exhaust treatment system serial # :

	baseline tests		**exhaust treatment tests**		**baseline**
test/option number:	1 2 3 4 5 6 7 8	intgrtd	1 2 3 4 5 6 7 8	intgrtd	repeat 1
engine/fuel variables:					
speed rpm					
torque N.m					
power kw					
fuel rate kg/hr					
intake/exhaust/engine variables:					
engine oil temp intake					
mnfld air temp ^{o}C					
exhaust mnfld gas temp ^{o}C					
exhst syst gas temp in ^{o}C					
exhst syst gas temp out ^{o}C					
inlet mnfld vac mm H_2O					
exhaust mnfld press mm H_2O					
exhst syst inlet press mm H_20					
exhst syst outlet press mm H_2O					
exhst syst press drop mm H_20					
air flow:					
Pbarometric (ambient) mm H_g					
ambient air temp ^{o}C					
ambient air RH %					
actual air flow kg/hr					
exhaust gas analysis (dry vol basis):					
CO2 %					
O2 %					
CO ppm					
NO ppm					
NO2 ppm					
SO2 calc from fuel S ppm					
SO2 measured ppm					
THC as CH4 ppm					
particulate analysis (dry basis):					
dry exhaust gas flow kg/hr					
moisture produced flow kg/hr					
total wet gas flow kg/hr					
wet gas sample flow kg/hr					
DPM concentration*1 mg/m^3					
BG 2 diluted concntrtn mg/m^3					
EQI/ventilation (dry basis)/ESE:					
EQI test -					
EQI worst condition -					
ventilation required*2 m^3/min					
EQI integrated -					

ESE integrated %					

*1 isokinetic, centre-line undiluted DPM sampling
*2 equivalent to AQI = 3.0

APPENDIX IIIB **FINAL EXHAUST TREATMENT TECHNOLOGY TEST RESULTS (IMPERIAL EXAMPLE)**

Date:
engine manufacturer: exhaust treatment system manufacturer :
engine model #: exhaust treatment system part # :
engine serial #: exhaust treatment system serial #:

	baseline tests		**exhaust treatment tests**		**baseline**
test/option number:	1 2 3 4 5 6 7 8	intgrtd	1 2 3 4 5 6 7 8	intgrtd	repeat 1
engine/fuel variables:					
speed rpm					
torque lb.ft					
power bhp					
fuel rate lb/hr					
intake/exhaust/engine variables:					
engine oil temp intake					
mnfld air temp ^{o}F					
exhaust mnfld gas temp ^{o}F					
exhst syst gas temp in ^{o}F					
exhst syst gas temp out ^{o}F					
inlet mnfld vac in H_2O					
exhaust mnfld press in H_2O					
exhst syst inlet press in H_20					
exhst syst outlet press in H_2O					
exhst syst press drop in H_20					
air flow:					
Pbarometric (ambient) mm H_g					
ambient air temp ^{o}F					
ambient air RH %					
actual air flow lb/hr					
exhaust gas analysis (dry vol basis):					
CO2 %					
O2 %					
CO ppm					
NO ppm					
NO2 ppm					
SO2 calc from fuel S ppm					
SO2 measured ppm					
THC as CH4 ppm					
particulate analysis (dry basis):					
dry exhaust gas flow lb/hr					
moisture produced flow lb/hr					
total wet gas flow lb/hr					
wet gas sample flow lb/hr					
DPM concentration*1 mg/m^3					
BG 2 diluted concntrtn mg/m^3					
EQI/ventilation (dry basis)/ESE:					
EQI test -					
EQI worst condition -					

ventilation required*2 scfm					
EQI integrated -					
ESE integrated %					

*1 isokinetic, centre-line undiluted DPM sampling
*2 equivalent to AQI = 3.0

APPENDIX IV

EQUIPMENT DOCUMENTATION FOR EXHAUST TREATMENT TECHNOLOGY TESTS (EXAMPLE)

ENGINE:	manufacturer..... model..... number..... serial number..... IDI or DI..... turbocharged..... aftercooled..... number of cylinders..... cylinder arrangement..... bore..... stroke..... engine displacement..... rated horsepower..... rated speed..... peak torque speed..... idle speed..... maximum governed speed..... type of engine cooling.....
FUEL INJECTION SYSTEM:	injection pump manufacturer... type..... model number..... serial number..... from injection pump manual: fuel injection timing..... timing adjustment means.....
FUEL SPECIFICATIONS INCLUDING EXCEPTIONS TO CAN.CGSB 2-3.16:	% carbon content by weight.. % hydrogen..... % sulphur..... specific gravity (water = 1).. cetane number or index..... exceptions: .....
AIR CLEANER: (dry type only)	manufacturer..... model number..... serial number.....
EXHAUST SYSTEM:	muffler manufacturer..... model number..... serial number..... exhaust pipe diameter.....
EXHAUST	manufacturer.....

TREATMENT: type.....
model number.....
serial number.....
part number.....
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