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STATUS OF CANADIAN IN-MINE DIESEL PARTICULATE FILTER FIELD TRIALS

By

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ABSTRACT

Following considerable laboratory studies concerning diesel particulate control systems for underground use, a Canadian program was initiated to implement practical, real-life systems. This program covers the application in seven mines throughout Canada, of a particulate control system, to 14 engine models from four engine manufacturers in 18 different vehicle types, for a total of 23 vehicles.

Partially funded by the Canadian National Research Council (NRC), this program required detailed analysis of operating cycles, maintenance variabilities and installation problems. This paper summarizes the work carried out to date to define real-world targets and the success achieved so far in attaining practical underground particulate control.

INTRODUCTION

With the advent of mechanisation in underground mining, specific problems arose from the use of internal combustion engines in limited ventilation areas.

Overall, diesel-powered equipment provides the best combination of safety, flexibility and production efficiency. The ability of a diesel-powered machine to easily transport itself enables redeployment of the machine to areas of a mine where production requires effort, without complications of cable length and cable relocations.

The benefits, however, must be weighed against the problems raised by exhausting toxic and irritating emissions into a confined environment.

To provide adequate protection in the workplace, stringent ventilation requirements exist. Also, considerable efforts have been made to reduce the levels of pollutants from mine vehicles.

Resulting from a collaborative effort between the Canadian Department of Energy, Mines and Resources, through CANMET, the United States Department of the Interior, through the U.S. Bureau of Mines and the Ontario Ministry of Labour, considerable information has been acquired on the nature of diesel exhaust emissions, methods of measuring these pollutants and improved means of controlling them. An Air Quality Index (AQI) has also been developed as a means of comparing pollution levels and emission control devices.

By means of the AQI, it can be demonstrated that the particulate matter present in diesel exhaust represents a significant health factor and its removal can lead to a 30 to 50% reduction in the AQI, or more.

Systems have been developed to remove the particulate matter by impingement or filtration and there is considerable documentation on these products which show removal efficiencies of over 70% (1, 2).

The diesel particulate wall flow element, produced by Corning Glassworks, consists of a monolithic ceramic honeycomb comprising parallel square cells, alternately plugged at the ends of the monolith. This plugging causes the exhaust gas to flow through the porous ceramic wall of the cells, which causes the particulate to be removed (See Figure 1). These wall flow ceramic elements, when canned, sealed and adapted become diesel particulate filters (DPFs), which exhibit filtration efficiencies of the order of 90% or more (3).

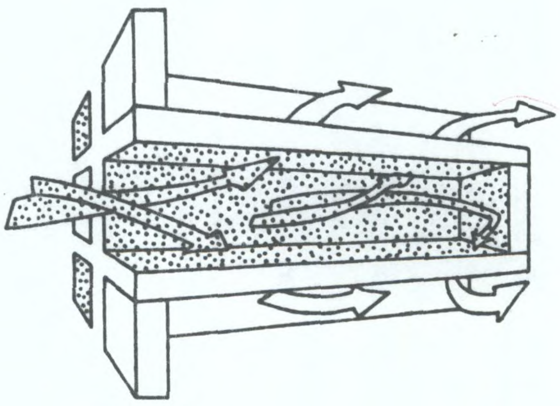

Figure 1 Ceramic element filtration principle.

The trapping or filtration process leads to an increase in backpressure due to coating or plugging of the porous trap wall. If the

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particulate is not removed the maximum backpressure allowed by the engine manufacturer will be exceeded with possible, subsequent damage to the exhaust valves and engine. The majority of work currently undertaken on diesel emission filtration systems, is the development of methods for removal of particulate. This cleaning process is referred to as regeneration.

Particulate can be removed by raising the temperature to its point of ignition, then the particulate will partially or completely burn to gaseous components thereby being removed with a reduction in backpressure. If during the duty-cycle of an engine, this ignition temperature is reached for a sufficient length of time, then complete regeneration will occur and the backpressure will decrease. (See Figure 2)

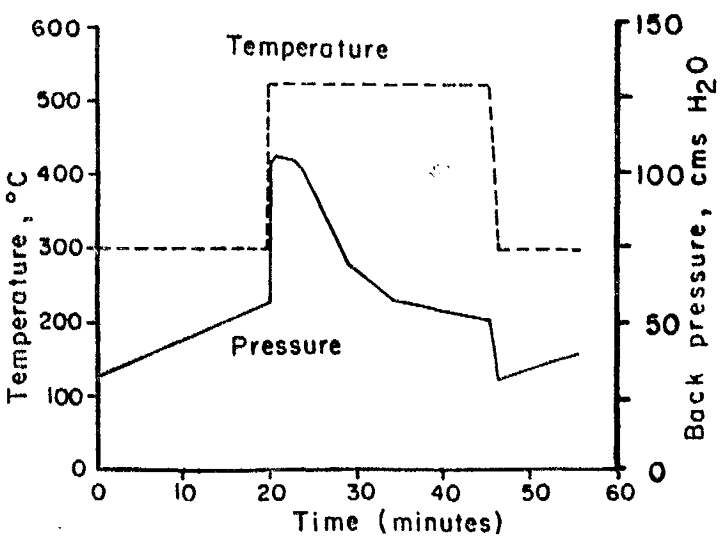

Figure 2 - Filter regeneration - simple cycle

In this mode, the filter will fall into a regular regeneration cycle with the backpressure rising and falling as the particulate collects and is then burnt off.

An unassisted or bare filter will regenerate at 500°C and above (4). Large vehicles, with high-load requirements can achieve these exhaust temperatures during the operating cycle, but it is unlikely that these vehicles represent more than 30% of those used in underground hardrock mining. One such system has been operating at INCO Mines in Sudbury for over 2500 hours (5).

For vehicles whose duty cycles produce lower maximum temperatures, it is necessary to raise the exhaust temperatures or to reduce the ignition temperature of the particulate. Particulate ignition temperature can be lowered by the use of a catalyst. The catalysts used are platinum group metal catalysts, base metal catalysts or fuel additives. In the last case, the catalyst is incorporated into the fuel, with subsequent deposition on the filter. The use of these catalysts is well documented and each has benefits and disadvantages. The regeneration temperatures of the various filter systems which have been evaluated (6, 7), are summarized below in the "system selection" section.

As mentioned earlier, the ability of the systems to filter is well documented but their application in underground hardrock mining is dependent on their ability to regenerate. For this reason, a program was undertaken by Engine Control Systems Ltd. (ECS), supported by the Canadian National Research Council, to demonstrate ceramic diesel exhaust filtration systems in seven underground Canadian mines on twenty-two vehicles. Various assisted and unassisted regeneration systems were to be evaluated and it was required to demonstrate the ceramic filters as efficient means of controlling diesel pollution in underground mines. The program is scheduled to take nearly three years and involves the three major makes of engines used in Canadian mines.

PROGRAM DEFINITION

The NRC program is divided into four phases: 1) technology transfer and program planning, 2) system assembly and installation, 3) data acquisition and monitoring, and 4) report finalization and recommendations.

The mines cooperating in this program are listed in Table 1. These mines have supplied the engines and vehicles to be studied as also listed in Table 1. These lists cover a representative cross-section of the Canadian Mining Industry. This table also provides information regarding filter size and catalyst material to be discussed below.

During the initial discussion of this proposal with the various mine representatives, considerable concern was raised over the likelihood of down time occurring. These concerns are quite valid in a high production industry such as Canadian mining, and, from the beginning it was made clear that emphasis would be placed on minimizing downtime.

Specifically, ECS undertook to:

1. provide ready-to-install systems to the mine and install or assist in the installation of such systems.
2. design the system and its various fittings, adaptors etc. in such a way as to make removal or replacement of parts a quick, simple operation. Filters are to be installed with quick release clamps similar to those used on other ECS products. Care to be taken to ensure the easiest possible access to parts such as bolts, and other hardware.
3. provide the mines with either spare filters

or some sort of a back up exhaust system so that in the event of filter blockage or damage, down time would be kept to a minimum.

4. train the operator and provide a simple routine for filter monitoring likely to take about five minutes per shift thus creating negligible production losses.
5. provide rapid troubleshooting should any problems arise. A team has been ready to travel to the mines at most times and ECS maintains sufficient spare instruments, parts etc. to ensure that no delays occur if a problem develops.

SUMMARY OF IN-MINE STUDIES

ANTICIPATED CHALLENGES

From previous research and the company's subsequent experience, it was apparent that several problems would arise, including the major practical consideration of regeneration of the DPFs. There is considerable variation in an engine's exhaust temperature profile. The profile may change from:
1. engine to engine 2. exhaust bank to bank 3. vehicle to vehicle 4. operator to operator 5. cycle to cycle.

In addition to these variations, certain engines such as the Detroit Diesels, have an inherently low exhaust gas temperature thus making in-situ regeneration difficult. Many utility vehicles have similarly low exhaust gas temperatures as a result of the light loads placed upon them. In some cases none of the proposed "unassisted" regeneration systems would work. Consideration was therefore given to various complementary "assisted" regeneration systems.

It is very important, therefore, to build up statistical information relevant to such concerns regarding the use of filters before these systems can be released on a commercial basis.

To obtain the necessary statistical record of the interaction of these major variables and relate them to engine operating variables, temperature, RPM, torque and backpressure, cycle results are obtained on a data recorder for each participating machine. This test equipment is housed in a protected area where the effects of temperature, vibration, dust and mechanical shock are minimal. The measured variables are determined with standard, readily available, engine test instrumentation connected to the recorder.

The second practical consideration for commercialization is backpressure. Exhaust conditioners currently used, such as monolithic catalytic purifiers and fume diluters, do not have a tendency to plug, since they are designed to allow the smoke to pass straight through. Since, as shown earlier, trapping causes an increase in backpressure, a filter system needs the capacity to operate for many hours before reaching the engine manufacturer's

Table 1

Engine/Mine/Vehicle/System/Filter Selection

ENGINE	MINE	VEHICLE	FILTER SIZE	CATALYST
F13L 413 FW	COMINCO (BC)	JDT 426 TRUCK	2X15"X14"	NO
F10L 413 FW	COMINCO (BC)	JS 500 SCOOP	2X15"X14"	YES
	BRUNSWICK (NB)	WAGNER ST8A	2X11¼"X14"	YES
F8L 413 FW	FALCONBRIDGE (ONT)	JS 500 SCOOP	2X11¼"X12"	YES
	FALCONBRIDGE (ONT)	JS 500 SCOOP	2X11¼"X14"	YES
	KIDD CREEK (ONT)	ST8A	-	-
F8L 714	BRUNSWICK (NB)	WAGNER 2DT TRUCK	2X11¼"X12"	NO
	INCO (ONT)	JS 500 SCOOP	2X11¼"X12"	YES
F6L 413 FW	KIDD CREEK (ONT)	ST5 SCOOP	2X11¼"X12"	YES
F6L 912 W	INCO (ONT)	BOOM TRUCK	1X11¼"X12"	YES
3304 NA	INCO (ONT)	D4 DOZER	1X11¼"X14"	YES
3304 T	RIO ALGOM (ONT)	JS 350 SCOOP	1X15"X14"	YES
3306 TA	FALCONBRIDGE (ONT)	JCI TRUCK	1X15"X14"	YES
	BRUNSWICK (NB)	ST8A	1X15"X18"	YES
3208	COMINCO (BC)	TELEDYNE CARRIER	1X11¼"X12"	YES
FORD 545	KIDD CREEK (ONT)	TRACTOR	1X5.66"X8"	YES
6V 71 N	RIO ALGOM (ONT)	ST6C	2X11¼"X14"	YES
8V 71 N	RIO ALGOM (ONT)	JDT 426 TRUCK	2X11¼"X14"	YES
		JS 800 SCOOP	2X11¼"X14"	YES
	DENISON (ONT)	JCI 600 SCOOP	2X11¼"X14"	YES
		JDT 426 TRUCK	2X11¼"X14"	YES
	KIDD CREEK (ONT)	ST8A	2X11¼"X14"	YES

maximum allowable backpressure.

Another important matter is the need to avoid breakage due to mechanical or thermal shock. During the early evaluations of ceramic filters, there were a number of failures caused particularly by high thermal gradients and failures of packing materials. Since then, improved quality, better materials and a better understanding of the effect of oxygen levels, particulate buildup, temperature and ceramic element length/diameter ratio, have considerably reduced such failures. Experience in the highway application suggests that such problems can be avoided. This mining fleet trial is being undertaken to establish that ceramic filters can be used for over 2000 hours with regular regeneration and good filter reliability.

Table 2 shows a theoretical breakdown of diesel vehicles in Canadian underground mines. The table permits a theoretical projection of vehicles which will operate with filter systems. The last category indicates that ceramic filters, even with catalysts, will not be useable on a large number of vehicles. Although these vehicles represent a large proportion of the mine vehicle population, the significance in terms of pollution is much lower since most vehicles are of low horsepower and usually operated in areas of high ventilation. Nonetheless, development projects are being pursued to develop regeneration systems for this type of vehicle also.

EXPERIMENTAL EVALUATIONS

All evaluations were carried out with permission of the appropriate mining authorities and in full consultation with the original equipment manufacturers who agreed to support this project.

As mentioned above, temperature/load/RPM profiles are recorded for each vehicle. From data already collected, it was possible to determine which filter system would be the most suitable for each vehicle. The engine cycle was then reproduced in a test cell so that the system could be evaluated for that duty-cycle. If the system regenerated successfully and regularly in the test cell, the system was then installed on the vehicle at the mine site.

The filter system was further evaluated on the vehicle before going into service.

Thermocouples and backpressure transducers were installed before and after the filter for initial monitoring of the backpressure and temperature cycles. Subsequently, each vehicle was fitted with pyrometers and backpressure alarm systems which indicate if the filter is operating out of its desired range.

Once in service, the filter system on each vehicle was closely monitored for one month, following which a further complete evaluation took place. At this time, any variation from initial backpressure was evaluated. If no significant change was

Table 2

Breakdown of projected filter systems on Canadian underground diesel mining vehicles

ENGINES	BARE OR CATALYSED FILTERS			MACHINES REQUIRING MORE COMPLEX SYSTEMS					
	LHD	PRODUCTION VEHICLE	LIGHT DUTY	GENERAL UTILITY	TRACTOR	GRADER	DOZER	PERSONNEL CARRIER	SUPPORT VEHICLE
DEUTZ									
F5L912W		27							
F6L912W		28		886					
F6L413FW		28						105	
F8L714	161	180							
F10L413FW	298	38							
F10L714	124								
F12L413FW	125								
CATERPILLAR									
3204							80		
3304	96	36		98		62			
3306TA		70							
3306NA	144	50							
DETROIT DIESEL									
6V71N	62								
8V71N	63								
OTHER					451	20		100	246

noted, then the vehicle was allowed to operate with the system for a further three months, when it was again checked. If, at this stage, the system was functioning well, the vehicle began long-term tests to establish the life of the filter(s).

Most testing in the mining industry had been done on Deutz engines, including 6, 8 and 10 cylinder 714 or 413 series engines. Deutz engines were, therefore, the first engine type studied in this program.

Detroit Diesel engines were subsequently studied. Although there is little experience with filters on these engines in underground mines, considerable information is available from the heavy duty highway development, where the DDA engine is the main engine used in bus studies.

As Caterpillar engines had little data generated on the effects of filter, a specific program was carried out to determine the effects of filters on the emissions and regeneration characteristics of these engines.

ANALYSIS OF TEMPERATURE TRACES

Time temperature traces were obtained and converted into histograms (see examples in Figures 3 and 4).

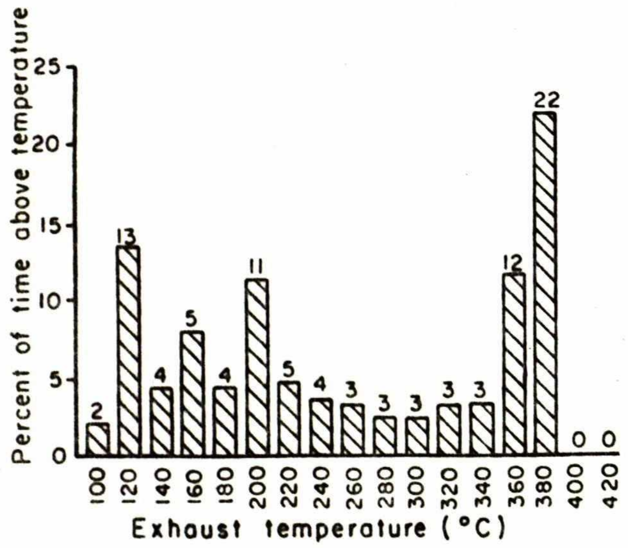

Figure 3 - Temperature histogram - JDT 426 truck with a DDAD 8V-71 engine.

Several points became apparent:

1. common, significant temperature differences of up to 100°C existed between banks of V-engines,
2. the working conditions also varied depending on the task being undertaken. Several traces were required to establish the true "average condition", and
3. the best regeneration aid is ramp climbing where the temperatures were sufficient to ensure regeneration.
4. production expediency also leads to differing temperatures. For example, one machine was operating satisfactorily in production with three unusually cold cylinders.

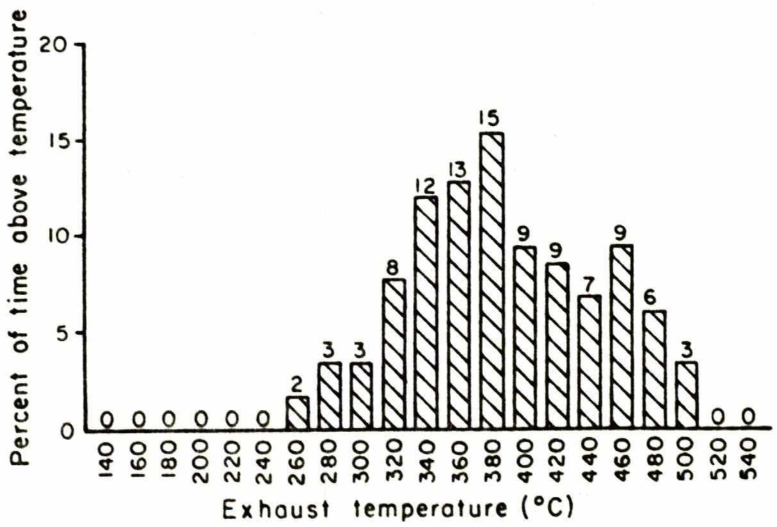

Figure 4 - Temperature histrogram - JS500 Scoop with a Deutz F8L714 engine.

To summarize the temperature analysis, it became apparent that system selection should be based upon worst case use. This invariably leads to the choice of a catalysed unit to ensure a regeneration possibility in light duty applications.

DYNAMOMETER EVALUATION

Following the data collection from the in-service base vehicle, the operating cycle, defined as rpm and exhaust temperature, is reproduced on the engine test dynamometer. This is achieved by real-time closed-loop control of RPM and load to achieve duplicate conditions.

The rationale for this is to determine the exact temperature time relationship for regeneration. For example, given the thermal inertia and time to clean the larger 15 inch filter, the duration of power spikes can provide high temperatures for insufficient cleaning time.

Therefore, consideration must be made in selecting a suitable filter system to ensure that the system will function through the expected range of duty cycles and not just the hottest most favourable case.

An allowance must also be made for the effects of maintenance on the exhaust temperature. In general, as the engine falls out of tune, a decrease in exhaust temperature is generally experienced with time.

SYSTEM SELECTION

Based upon both the available data and engine dynamometer tests, the following selection criteria were used to choose the preferred system.

Category A: vehicles whose exhaust temperatures exceeded 500°C for a continuous period of 5 minutes per hour.
Category B: vehicles whose exhaust temperatures exceeded 400°C for a continuous period of 5 minutes per hour.
Category C: vehicles whose exhaust temperatures rarely reached 400°C.

Systems available for selection were categorized as follows:

System A uncatalysed ceramic suitable for regeneration by temperatures in excess of 520°C
System B catalysed ceramic for temperatures in excess of 440°C for base metals, and 400°C for noble metals.
System C catalysed ceramic with regeneration aid.

FILTER SIZES

Following discussions with the various engine manufacturers concerning the backpressure limitation on each engine and also the flow characteristics of the filters available, data was produced showing engine type and backpressure curves for various sizes. This data is shown in Figures 5 and 6.

A rate of build up with particulate loading was developed and this is shown is figure 7.

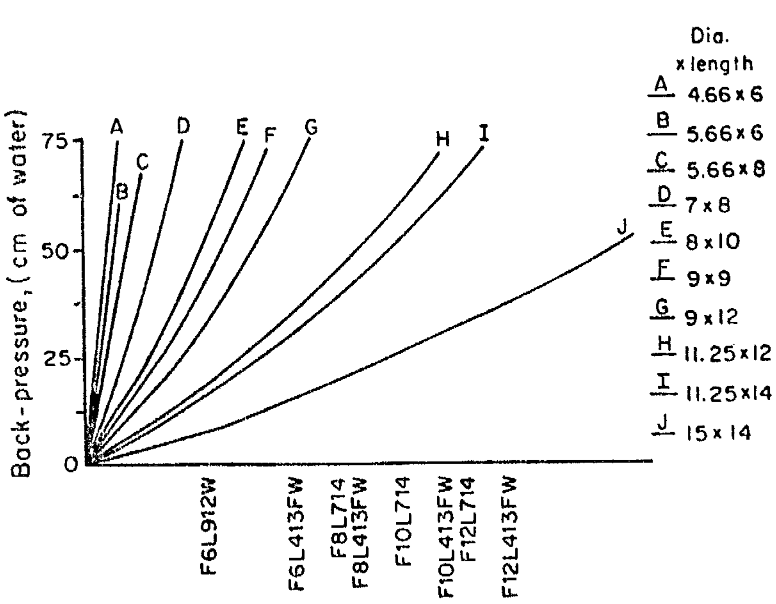

Figure 5 - Filter sizing for Deutz engines.

INSTALLATION

A number of criteria were considered before the installation configuration was

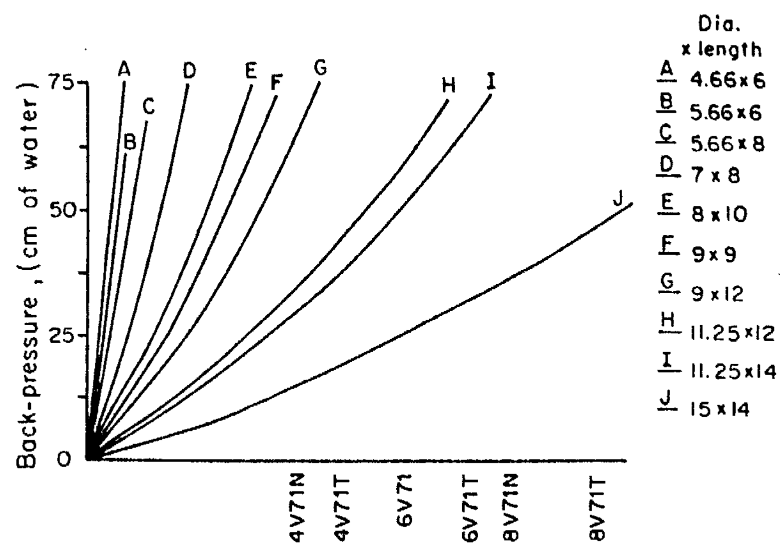

Figure 6 - Filter sizing - Detroit Diesel engines.

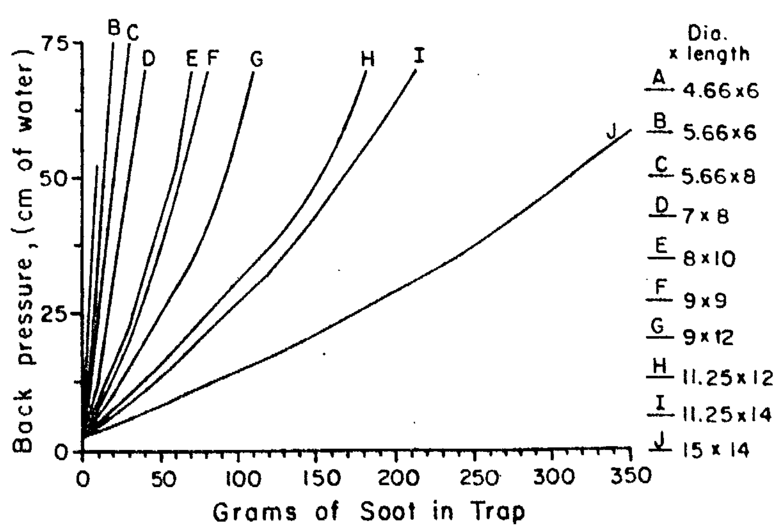

Figure 7 - Backpressure vs. soot loading.

finalized. These can be summarized as follows:

1. The filter must be mounted as close as possible to the engine.
2. The filter must be shielded from rock fall, wall scrapes, roof scrapes and machine damage.
3. The machine must be shielded from filter heat buildup.
4. Space on the vehicle is at a premium.
5. Routine maintenance must not be obstructed.
6. Local modification to the vehicles frequently already used the available space.

A typical installation is shown in Figure 8.

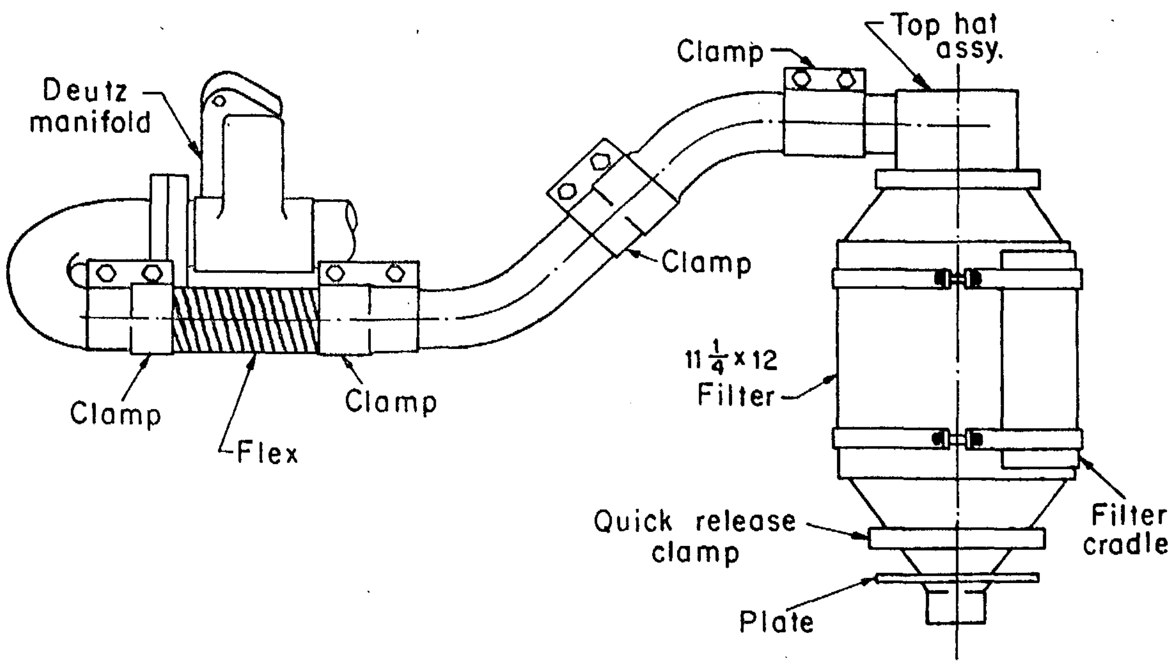

Figure 8 - Installation in a JS500 Scoop.

EMISSIONS RESULTS ON ECS CATALYSED CERAMIC FILTERS

To determine the emission effects of the ECS catalysed filters (Purifilters), they were evaluated on a Deutz F8L413 engine using the simulated LHD cycle referred to as the MTU MOD5 cycle, the exhaust temperatures for which are high enough to produce filter regeneration.

AMES MUTAGENICITY ASSAY

Particulate samples from the Purifilters were analyzed using tester strain TA-98 with and without metabolic activation. No baseline Ames data was obtained in this program, but a baseline from previous work on the same engine and same cycle are provided for comparison as follows:

Table 3

Ames mutagenicity assay

Sample	Soluble Particulates mg/m^3	Mutagen Conc't'n $Rev./m^3$	Specific Activity Rev./ug
Without Activation			
Baseline	14.5	36,350	2.5
Purifilters	2.09	3,552	1.7
With Activation			
Purifilters	2.09	1,650	.79

The Purifilters reduced the revertants per cubic metre of exhaust by 90% and also reduced the specific activity by 47%.

These results suggest that there would not appear to be a health-impacting concern from the use of this catalyzed system.

EXHAUST QUALITY INDEX REDUCTION

Change in one toxic component of diesel emissions is invariably accompanied by changes in others, yielding evaluation of the net toxicity effect elusive. There has been some confusion about one effort to come to grips with this problem - hence the following discussion.

In 1978, CANMET medical contractors formulated a single expression for the comprehensive toxicity of diesel emissions from examination of 1600 relevant literature citations of the time.

That expression is:

$$AQI = \frac{CO}{50} + \frac{NO}{25} + \frac{RCD}{2} + 1.5\left[\frac{SO2}{3} + \frac{RCD}{2}\right] + 1.2\left[\frac{NO2}{3} + \frac{RCD}{2}\right] \quad \text{.....Eq 1}$$

where each gas concentration is measured in ppm, and the Respirable Combustible Dust (RCD) is measured in mg/m3. The RCD limit for soot alone is a suggested 1.5 mg/m3, but that for RCD is set at 2 to compensate for an additional 33% of other repirable combustible material estimated to be included on a filter sample. Further, it was pointed out that if sulfuric acid could be measured separately in a laboratory, then and $H_2SO_4/1$ term could be added.

The recommended maximum value of the single expression AQI for a suitable ambient environment is 3. If the same expression is used to calculate the Index for undiluted exhaust gas emissions, the value is called the Exhaust Quality Index (EQI). The ventilation dilution ratio (fresh air flow/exhaust gas flow) is then EQI/3 in order to determine the ventilation rate required for an AQI = 3 max. The denominator terms should not be changed if the ACGIH-TLVs are changed (note that the TLV-SO2 has recently been reduced to 2).

As a result of peer recommendations, the contractors were subsequently requested to consider separating the gaseous and particulate health effects. This effort (8) resulted in the following two-equation criterion:

$$AQIgas = \frac{CO}{50} + \frac{NO}{25} + \frac{NO2}{3} = 1 \text{ or less} \quad .....\text{Eq } 2$$

$$AQIparticulate = \frac{RCD}{2} + \left[\frac{SO2}{2} + \frac{RCD}{2}\right] + \left[\frac{NO2}{3} + \frac{RCD}{2}\right] = 2 ...\text{Eq } 3 \text{ or less}$$

That same reference concludes however, that little change results from the use of the single compared to the dual criterion as maybe noted from analysis of the EQI values in Table 4 below. Consequently, in the interests of simplicity and continuity, and in order to avoid a proliferation of criteria based on the AQI concept, CANMET continues to employ and recommend the use of only the above expressions with particular emphasis on the use of the single expression criterion. It should be noted that it was not intended that the two parts of the dual criterion be added together.

Consequently, calculation of the toxicity of three baseline emissions tests and three catalyzed Purifilter tests, yields the results given in Table 4.

The results of Table 4 below indicate that the catalyzed ceramic Purafilters proved to be efficient devices for reducing the toxicity of diesel emissions. Soluble and insoluble particulate emissions were reduced by greater than 98%. Total hydrocarbons measured as CH4 were reduced by 40%. While some sulphate storage did take place, the fuel sulphur conversion was less than 10%.

Table 4

Average Comprehensive Toxicity
Baseline vs Catalyzed Purafilter
MTU-MOD 5 Cycle

Constituent	Baseline	Purafilter
CO ppm	228	225
NO ppm	525	550
NO2 ppm	117	91
SO2 ppm	118	109
RCD mg/m3	79	0.9
EQI (Eq 1)	277	119
EQIgas (Eq 2)	65	57
EQIparticulate (Eq 3)	217	86

In addition to the above significant Ames test and individual component reductions, the use of the catalyzed Purafilter element resulted in a [(277 - 119)/227] X 100 = 57% reduction in comprehensive toxicity relative to the baseline conditions using the single expression EQI criterion. This corresponds to a substantial air quality improvement of [(1/119 - 1/277)/(1/277)] X 100 = 133%.

RESPONSES FROM DIESEL VEHICLE OPERATORS

The responses from vehicle operators thus far have been generally favourable. These pertain to removal of the characteristic diesel odour, reductions in noise and soot, and better visibility which is in turn linked with improved safety and possibly improved production. However, these views bear further attention and comment.

Firstly, for the initial days of operation of a filter unit, the smell emanating from the Interam sealing material as it cures in-situ, is most unpleasant. This is despite prebaking of the assembled units. Preliminary studies indicate that this is solely a cosmetic problem. A program of canning procedure modification has been undertaken to reduce this initial odour problem to a minimum.

Secondly, when the majority of the more familiar odours have been removed by a hot uncatalyzed filter, the exhaust gas displays a mild SO2 odour which is ordinarily masked. Depending on one's point of view, this could be considered as a useful indicator, but requires that an explanation be given to operators. The odour levels generated are likened to those encountered with propane-powered vehicles.

Also, it was anticipated that the filter would remove blue smoke as well as black smoke, especially on start-up. Although blue smoke is diminished somewhat with catalyzed units, this is not the case with uncatalyzed systems.

Further, as it had been shown that exhaust noise can be substantially reduced by a ceramic filter, it was assumed that such a system would contribute to a reduction in total vehicle noise. However, for the initial installations, the contribution of exhaust noise to the total was found to be small and little overall noise reduction was indicated. Some mines however, report significant reductions for this largely machine-dependent variable.

Finally, the principle impression is that black smoke is reduced. Subjectively, the smoke levels from well-adjusted machines rank only slightly worse than filter-equipped machines. Tests indicate substantial soot reductions however. Smoke levels are generally perceived by headlight illumination. But heading opacity in this case can be due to agents other than combustion-generated soot, such as: airborne ore dust, blue smoke, evapourated lubeoil or hydraulic oil from hot surfaces, and drill oil mist. Also, operators class exhaust smoke and crankcase breather smoke together. One filter-equipped machine was shutdown due to perceived excessive exhaust smoke which was ultimatley traced to almost totally blocked air cleaners, and another was shut down due to what was ultimately determined to be crankcase breather smoke.

CONCLUSIONS

As this program continues with the fleet trial, the data base expansion will enable a better overall impact analysis. That the product is of interest to the mine operators is evidenced by the high level of cooperation given to this program.

To date, the ceramic filters have stood up well in in-mine service. There have been some filters damaged by rock fall, but otherwise the ceramic and the installations have performed well. Some initial installations are now over the 2000 hours of successful operation.

No regeneration problems have occurred, due in part to the careful selection procedures, attention to installation details, and in the main due to the safety margin supplied by the catalyst coating. Machines operating with the catalysed filters have demonstrated flat back-pressure curves and good smoke control with minimal effects on the vehicle.

The transition from the laboratory to the real world is revealing interesting aspects that are specific to the use of filters and benefits furnished by low particulate mining vehicles.

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REFERENCES

1. Howitt, J.S., Elliot, W.T., Mogan, J.P., Dainty, E.D., "Application of a Ceramic Wall Flow Filter to Underground Diesel Emissions Reduction"; SAE paper 830181.
2. Weaver, C.S., et al, "Feasibility of Retrofit Technologies for Diesel Emission Control"; SAE paper 860 296.
3. Gulati, S.T., "Strength and Thermal Shock Resistance of Segmented Wall Flow Diesel Filters"; SAE paper 860008.
4. Dainty, E.D., Mogan, J.P., Mitchell, E.W., Lawson, A., "The Status of Total Diesel Exhaust Filter Development for Underground Mines"; CIM Special Volume 36, Paper 31, Pg. 401.
5. Dainty, E.D., et al, "Characterization of Ceramic Diesel Exhaust Filter Regeneration in a Hard Rock Mine"; CIM Special Volume 36, Paper 27, Pg. 348.
6. Thomas, L.R., Stekar, J.J., "Catalytic Trap Oxidizer for Diesel Particulate Control"; Proceedings CIM 4th M/E Plant Engineering and Maintenance Conference, Feb. 1985.
7. Lawson, A., et al, "Performance of a Ceramic Diesel Particulate Trap Over Typical Mining Duty Cycles Using Fuel Additives"; SAE paper 850150.
8. French, I.W. and Mildon, C.A. "Health Implications of Exposure of Underground Mine Workers to Diesel Exhaust Emissions - an Update." CANMET Contract Report OSQ-82-00121, 607 pages, April 1984.