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ABSTRACT

Results of a laboratory assessment of catalyzed ceramic diesel particulate (DPFs) filters are reported. Catalyzed DPFs are shown to substantially reduce diesel particulate emissions, carbon monoxide (CO) and gaseous hydrocarbons as well as particulate ignition temperatures. Sulfate production is discussed in relation to sulfates presently emitted into the mine environment.

Field experience is reported on the application of the ceramic diesel particulate filter to control diesel particulate emitted from underground diesel powered vehicles. The vehicle has been operated in mine production service over typical load-haul-dump duty cycles. Field tests have been carried out using the filters assisted with both fuel additive and precious metal catalyst coating techniques. The structural integrity of the filter appears satisfactory with approximately 250 hours of field experience. Both manganese fuel additive and precious metal catalyst coating were shown to provide satisfactory regeneration assist. Exhaust backpressures over a 250 hour test were lower than the original exhaust system comprising an exhaust catalytic purifier and muffler in series.

DIESEL ENGINES HAVE BEEN USED EXTENSIVELY IN UNDERGROUND HARD ROCK MINING OPERATIONS, and to a lesser extent, in gassy (coal) mine operations, as a result of their effect in improving the tonnage of ore produced by the mine. There is current interest in expanding diesel operations in coal mines to improve production rates and transport of men and materials. In many mines, however, production rates with diesel equipment are ventilation limited, controlled by regulation which specifies minimum ventilation rates per horsepower of diesel engine. This regulation reflects concern over the exposure of mine workers to diesel exhaust emissions requiring ventilation to "safe" exposure limits. This concern was reflected in a Royal Commission Report on the health and safety of mine workers in 1976(1)*. While ventilation is required to reduce concentrations of individual diesel exhaust components to below their TLV's (threshold limit values), a potential synergistic effect on the human respiratory system has been suggested (2) where the diesel particulate acts as a carrier of other toxic components, such as adsorbed PAH's (polynuclear aromatic hydrocarbons), NO_2, or H_2SO_4, deep into the lung.

In 1980, the health concerns of the increased use of diesel equipment in underground mines led to the formation of a collaborative research panel comprised of the U.S. Department of the Interior, Bureau of Mines, the Canada Centre for Mineral and Energy Technology (CANMET), and the Ontario Ministry of Labour. The panel coordinates research efforts in underground diesel emission control between Canada and the United States. The agencies have provided research funding and program direction to study the effectiveness of present day diesel emission control devices, and to foster the development of improved emission control systems. The panel especially recognized the need for developments in the area of diesel particulate control. An optimum emission control system mounted on board the

*Numbers in parenthesis designate References at end of paper diesel vehicle has been selected that involves the use of a regenerative or self-cleaning particulate filter.

In an earlier SAE paper (3) work funded by the Bureau of Mines, was described which discussed developments related to the use of a ceramic diesel particulate filter to reduce particulate emissions from a heavy duty mines diesel engine. The filter was shown to be effective in reducing particulate emissions by 80-90%, based on laboratory test results. In addition, the use of EGR (exhaust gas recirculation) was shown to reduce NO_x emissions without increase in particulate emissions normally seen with application of this technique. Although exhaust temperatures were increased with EGR application, the reduced oxygen content in the exhaust, together with the increased rates of particulate entering the filter, negated effective filter regeneration from occurring over vehicle duty cycles typically found in underground mines. Further studies of ceramic filter regeneration over typical mine duty cycles were reported in a 1984 SAE paper (4). The use of fuel additives such as copper or manganese-copper were found to promote successful ceramic filter regeneration in engine dynamometer tests which simulated LHD (load-haul-dump) mine vehicle operations. The practicality of the ceramic filter as an emission control device for underground diesel engines was becoming more promising, since continuous filter regeneration was apparent over repetitive LHD mine duty cycles, and effective particulate emission control was being achieved.

The present paper, reports on an expansion of these studies, conducted under the auspices of the U.S. Bureau of Mines Program, to test the effectiveness of catalyst coated ceramic filters as a regeneration aid. Catalytic filters are known to lower the ignition temperature of collected soot. It was also our purpose to advance the program to field testing under mine production conditions, as an important step toward commercial introduction of filters into mining operations. Field test results are described, and various filter regeneration technologies for application to mining diesels are discussed. Best available technology is described relative to application to various different mining operations involving the use of diesel engines, and the opportunities for application of particulate filters to coal mine diesels is discussed.

EQUIPMENT AND TEST PROCEDURES

ENGINES - The engine used for the engine dynamometer studies was a Deutz F8L 413 FW indirect injection diesel engine rated at 133kW at 2300 rpm. This engine, together with the Deutz F8L 714 is in common use underground. Field testing was carried out using the Deutz F8L 714 engine.

ENGINE DYNAMOMETER TEST BED - The engine was coupled to an Eaton Model AD-8121 eddy current dynamometer capable of absorbing 373 kW at 5000 rpm, with an inertia of 46 lb. ft^2. The engine and dynamometer are controlled with a H.P. 1000 Series E computer coupled to an HP disc drive unit. A schedule builder allows rpm, torque, ramp time and stay time to be controlled to simulate vehicle duty cycles.

EMISSION MEASUREMENTS - Particulate collection utilized a diesel dilution tunnel system where the primary tunnal was 25.4 cm inside diameter and the secondary tunnel was 10.2 cm inside diameter. Maximum particulate filter temperature was maintained below 52°C. Dilution ratios were approximately 4.5:1. In this procedure the collected particulate sample filters are taken from the tunnel, conditioned (20°C, 50% R.H.) for 12 hours and weighed, then treated with methylene chloride to extract the soluble organic fraction. The remainder is the insoluble fraction. Gaseous emissions of CO, THC, and NO_x are measured by standard non-dispersive infra red, F.I.D. and chemiluminescent analyzers. Sulfate analysis was carried out using a controlled condensation method which has been described elsewhere (5).

DUTY CYCLES - A number of mine vehicle duty cycles, representative of LHD mining operations have been assembled from field data, and reproduced on the computer controlled engine test bed. Details of these cycles have been reported elsewhere (3),(4). They represent different conditions of vehicle operation from more lightly loaded to heavily loaded cycles. They have been designated MTU MODS 1, 2, 3 and 4 in increasing order of load factor, and have average exhaust temperatures of 359°C, 390°C, 407°C and 429°C, respectively. Testing of the catalyzed diesel particulate filter was carried out over such transient duty cycles, and also under steady state engine conditions.

ENGINE DYNAMOMETER TESTING OF CATALYZED DIESEL PARTICULATE FILTERS

FILTER DESCRIPTION - The ceramic diesel particulate filters were supplied by Corning Glass Works to Engelhard Corporation as segmented filters, 12" diameter x 12" long. Engelhard Corpora-

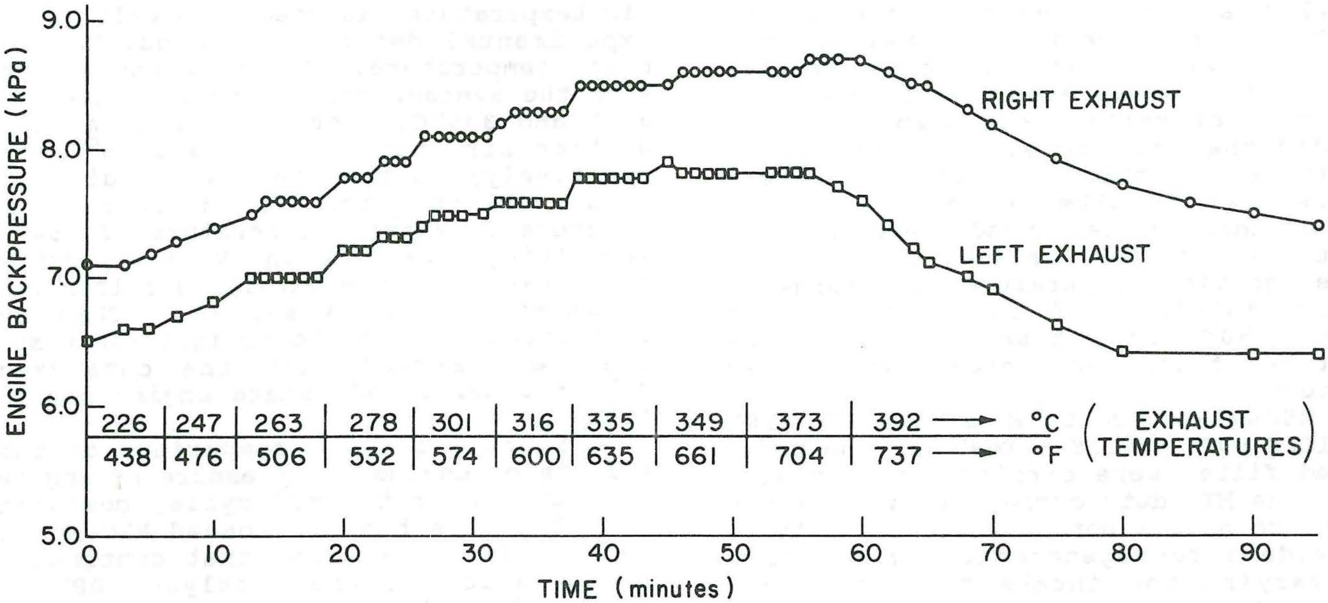

FIG. 1 FILTER IGNITION TEMPERATURE TEST. (Catalyzed Filter)

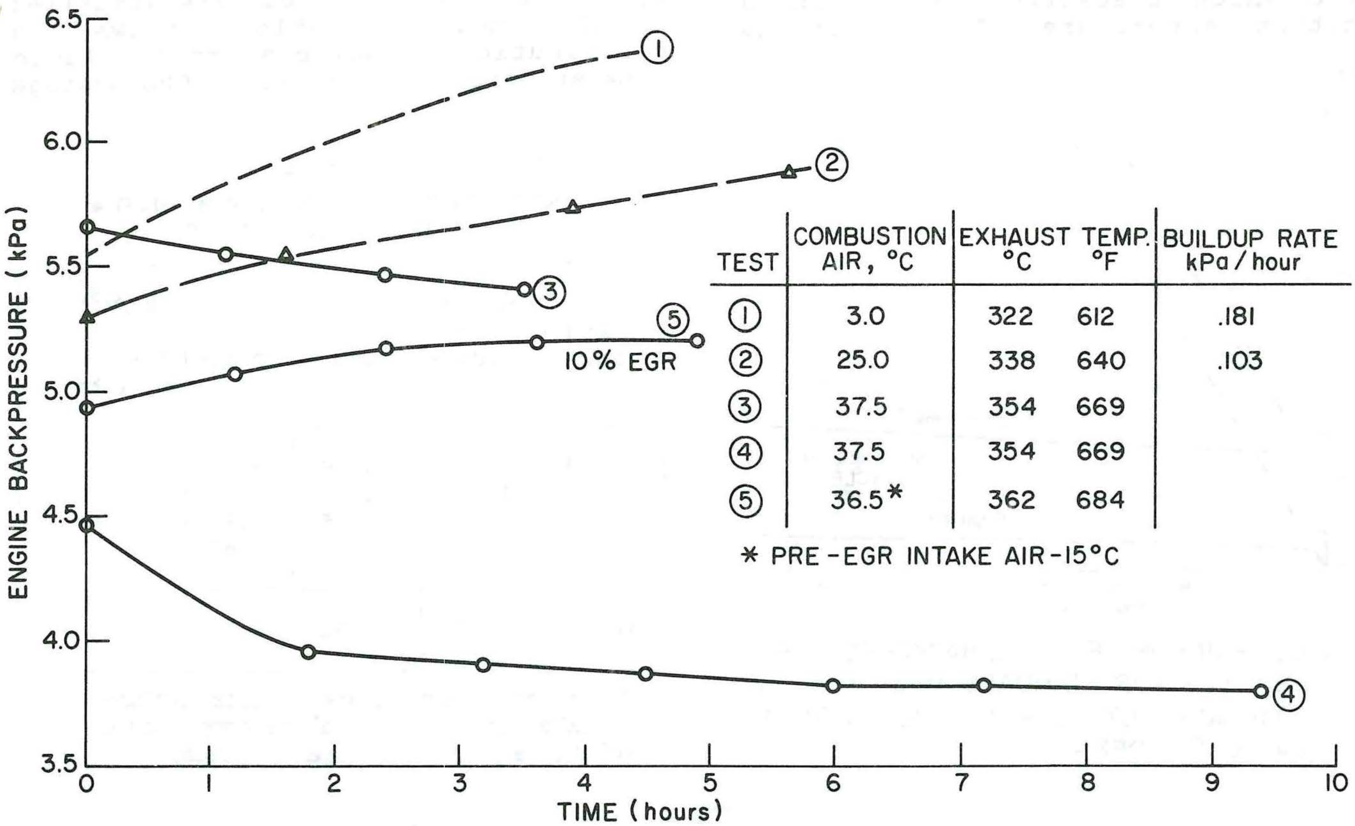

FIG. 2 COMPARISON OF FILTER BUILDUP WITH MTU CYCLE, AT VARIOUS COMBUSTION AIR TEMPERATURES. (Catalyzed Filter)

tion, coated them with a precious metal catalyst, packaged them, and shipped them to Ontario Research for testing on the engine dynamometer test bed. Two units were installed on the engine, one on each engine bank.

PARTICULATE IGNITION TEMPERATURES - To determine particulate ignition temperatures, progressive steady state engine tests were conducted with the catalyzed filter, in steps of increasing load and exhaust temperature, while observing engine backpressures. The threshold ignition temperature of the collected soot was determined when an equilibrium backpressure situation was reached as indicated when the engine backpressure stopped increasing, and, with further increase in exhaust temperature, the backpressure decreased, as the rate of particulate combustion exceeded the rate of particulate matter collected. Particulate ignition temperature test results shown in Figure 1 reveal that the catalyzed diesel particulate filter (DPF) reduced the particulate ignition temperature to a range of approximately 350°C to 370°C. This is about 150°C less than ignition temperatures found for non-catalyst coated filters.

REGENERATION OVER SIMULATED MINE VEHICLE DUTY CYCLES - Tests of the catalyzed filter were carried out initially over the MTU duty cycle. This cycle was found to have a borderline capability to provide auto-regeneration of the DPF. By varying the intake combustion air temperature and by applying EGR, it was possible to vary average exhaust temperatures over the MTU cycle from 322°C to 362°C which bracketed the threshold ignition temperature. Varying intake air temperature was used here only as an experimental device to manipulate exhaust temperature. Figure 2 shows that with the average exhaust temperatures of 322° and 338°C, (resulting from a combustion air intake of 3°C and 25°C respectively), auto-regeneration did not occur. (Plots 1 and 2). However, with an average exhaust temperature of 354°C (resulting from 37°C intake air), auto-regeneration of the catalyzed filter was achieved. (Plots 3 and 4). This is consistent with the lower ignition temperature observed with the catalyzed filter under steady state engine conditions.

Figure 3 shows a comparison of the effects on engine backpressure of engine operation over the MTU cycle, compared with the more heavily loaded MTU MOD 4 cycle. It is apparent that continuous regeneration of the catalyzed DPF is being achieved with the MTU MOD 4 cycle.

EMISSION CONTROL - Particulate testing was conducted over the MTU MOD 4 cycle with the catalyzed DPFs installed on the engine. Table 1 shows the distribution of soluble and insoluble exhaust particulate matter. The average

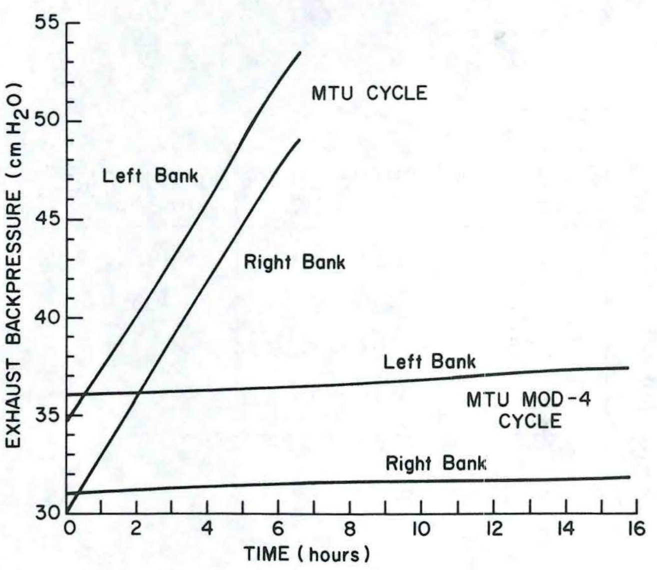

FIG. 3 COMPARISON OF ENGINE BACKPRESSURE PROFILES FOR STANDARD MTU CYCLE AND MTU-MOD 4 CYCLE WITH APPLICATION OF CATALYZED DPF's.

TABLE 1

PARTICULATE EMISSIONS FOR MTU-MOD 4 LHD CYCLE WITH CATALYZED DPF'S

Test No.	Particulate Concentration (mg/m^3)			
	Insoluble	Soluble	Total*	% Soluble of Total
1	1.44	1.78	3.22	55
2	1.63	1.44	3.07	47
3	1.73	2.16	3.89	56
4	1.06	1.44	2.50	58
Avg.	1.47	1.71	3.17	54

* Note: Total particulate results exclude sulfate fraction. Total is comprised of soluble and insoluble particulate.

TABLE 2

GASEOUS EMISSIONS OVER MTU CYCLE USING CERAMIC DPF REGENERATIVE APPROACH

Engine Conditions RPM/kW	Test Conditions	Nitric Oxide				Change %	Nitrogen Dioxide				Change %	Total Oxides of Nitrogen				Change %	Carbon Monoxide				Change %	Total Hydrocarbons				Change %
		ppm	g/hr	g/kW.h	g/kg Fuel		ppm	g/hr	g/kW.h	g/kg Fuel		ppm	g/hr	g/kW.h	g/kg Fuel		ppm	g/hr	g/kW.h	g/kg Fuel		ppm	g/hr	g/kW.h	g/kg Fuel	
2164/69.7 MTU Cycle	Cat. Ceram. Before Filter	417	331	4.75	15.5		43.1	52.5	0.752	2.45		460	560	8.03	26.2		113	84.0	1.20	3.43		84.0	35.6	0.51	1.66	
2164/69.7 MTU Cycle	Cat. Ceram. After Filter	326	258	3.71	12.1	-22	77.3	94.1	1.35	4.40	+79	403	490	7.03	22.9	-12	5.0	3.7	0.05	0.17	-96	40.1	17.0	0.34	0.79	-52
2164/92.4 MTU MOD 4 Cycle	Cat. Ceram. After Filter	348	272	3.03	9.8		153	183.4	2.04	7.36		501	601	6.68	24.1		5.4	4.0	0.04	0.16		16.0	6.7	0.08	0.27	

TABLE 3

$SO_4^{=}$, SO_2 MASS EMISSIONS CATALYZED CERAMIC TRAP

Engine Condit-ions (RPM % Load)	Test Conditions	SO_2				$SO_4^{=}$				Total Sulphur				% $SO_4^{=}$	% Total Sulphur of Theoretical
		ppm	g/hr	g/kWh	g/kg Fuel	ppm	g/hr	g/kWh	g/kg Fuel	ppm	g/hr	g/kWh	g/kg Fuel		
2200/100	Baseline									60.2	109*	0.807	2.91	2	96
"	Baseline									52.0**	94.1*	0.697	2.52	2	83
2200/100	Baseline									61.5	111*	0.822	2.97	2	98
	Average									60.8	110	0.814	2.94	2	97
2200/100	Cat.Corning	11.9	21.4	0.159	0.572	35.0	94.2	0.698	2.52	46.4**	116	0.857	3.09	75	74
"	Cat.Corning	19.6	35.1	0.260	0.951	38.0	101	0.748	2.74	57.6	136	1.01	3.69	66	92
2200/100	Cat.Corning	11.9	21.3	0.158	0.579	43.8	116	0.859	3.15	55.7	137	1.02	3.73	79	89
	Average	14.5	25.9	0.192	0.702	38.9	104	0.768	2.80	56.6	136	1.02	3.71	73	90
2200/31	Cat.Corning	24.2	45.5	1.08	2.71	2.5	7.0	0.167	0.417	26.7	52.5	1.25	3.13	9	100
2167/57 MTU	Cat.Corning	18.3	35.9	0.536	1.62	8.1	23.8	0.355	1.07	26.4	59.7	0.891	2.69	31	78
Cycle	Cat.Corning	21.3	41.8	0.624	1.88	9.2	27.1	0.404	1.22	30.5	68.9	1.03	3.10	30	90
	Cat.Corning	20.6	40.4	0.603	1.82	8.2	24.1	0.360	1.09	28.8	64.5	0.963	2.91	28	85
	Average	20.1	39.4	0.587	1.78	8.5	25.0	0.373	1.13	28.6	64.4	0.961	2.90	30	84
2167/57 MTU	Cat.Corning	20.7	33.2	0.503	1.48	9.2	22.1	0.335	0.988	29.9	55.3	0.838	2.47	31	72
Cycle	+ 15% EGR	22.8	36.6	0.555	1.64	11.9	28.6	0.433	1.28	34.7	65.2	0.988	2.92	34	83
+15% EGR	Cat.Corning	22.1	35.4	0.536	1.58	11.5	27.7	0.420	1.24	33.6	63.1	0.956	2.82	34	80
	Average	21.9	35.1	0.531	1.57	10.9	26.1	0.396	1.17	32.7	61.2	0.927	2.74	33	78
2150/73	Cat.Corning	10.6	17.7	0.192	0.708	25.3	63.5	0.689	2.54	35.9	81.2	0.881	3.25	70	92
	Cat.Corning	9.2	15.4	0.167	0.617	16.1	40.3	0.437	1.61	25.3	55.7	0.604	2.22	64	65
MTU MOD4	Cat.Corning	8.7	14.5	0.158	0.581	30.5	76.5	0.830	3.06	39.2	91.0	0.988	3.64	78	101
Cycle	Average	9.5	15.9	0.172	0.635	24.0	60.1	0.652	2.40	33.5	76.0	0.824	3.04	72	86

* Assumed 2% $SO_4^{=}$ ** Suspect data not in averages.

total particulate concentration (3.17 mg/m^3) is well below the baseline concentration of (~95 mg/m^3) and results in a particulate control efficiency of more than 90% (excluding sulphates).

Gaseous emissions of CO, THC and NO and NO_2 over the same MTU MOD 4 cycle are compared in Table 2 before and after the catalyzed filter. Substantial reductions in CO are apparent. Oxides of nitrogen for the MTU cycle were reduced only marginally (12%). Nitrogen dioxide emissons increased with the catalyzed DPFs over the same cycle.

Tests were also performed to determine emissions of SO_2 and H_2SO_4 over both steady state and transient engine conditions. Table 3 shows the results of steady state tests at various load/-speed conditions. For high engine loads, up to 69% of the fuel sulfur was determined to be sulfate. Since the mass balance accountability of the fuel sulfur was good (90% analysed), little storage of sulfate on the catalyzed filter occurs. At low engine loads, on the other hand, there is very little production of sulfate, and again, the accountability of sulfate is good. Sulfate production therefore appears to be a function of temperature.

Over the MTU cycle, Table 3 shows that about 30% of the fuel sulfur is converted to sulfate, but over the higher load factor MTU MOD 4 cycle 72% of the SO_2 is converted to sulfate. The high load factor experienced over this duty cycle together with associated high exhaust temperatures probably indicate that a less active catalyst which would still promote regeneration, but reduce sulfate formation would be appropriate.

CONCLUSIONS ON CATALYZED DIESEL PARTICULATE FILTER - It can be concluded that a precious metal catalyzed DPF offers good potential as a practical device for reducing particulate emissions from underground diesel vehicles. The device will likely auto-regenerate over many mine vehicle duty cycles, and considerably reduce soot emissions. Selecting the appropriate catalyst to allow regeneration, but minimize sulfate emissions is desirable. It is expected that sulfate emissions from underground vehicles using catalyzed DPFs would not be greater than what currently occurs with the use of precious metal coated flow-through exhaust purifiers, which are approved for use, and are extensively used on underground vehicles to reduce carbon monoxide emissions. The fate of sulfate emitted, from such emission controlled vehicles, in underground mines, has yet to be established. The use of low sulfur fuel together with the catalyzed filter is likely to be beneficial in minimizing sulfate emissions.

FIELD TESTS - Field tests of the ceramic DPFs were conducted in operating mines to evaluate durability and performance under actual operating conditions. Field tests were accomplished using two regeneration approaches: catalyzed DPFs and fuel additives.

Kidd Creek Mine in Timmins, Northern Ontario was selected for this demonstration. In 1981 this mine produced 4,076,000 tonnes of ore - primarily copper and zinc for subsequent milling at its refinery.

DPF INSTALLATION IN A MINE VEHICLE

The vehicle selected for testing was a typical LHD machine, a 4m^3 ST5 "Scooptram" powered by a Deutz F8L 714 air cooled diesel engine rated at 133 kW at 2300 rpm. The engine had been rebuilt, and had accumulated 2092 hours of operation prior to this test program. The original exhaust system employed on the LHD vehicle included an Engelhard 6 DM PTX catalyst in conjunction with a muffler on each exhaust bank.

In previous lab tests, DPFs were installed in the horizontal position, however, due to vehicle exhaust configuration and limited space, the DPFs were mounted vertically on the LHD. DPFs were attached solidly to the LHD mainframe by bolting the DPF flange directly to the vehicle floor. In this installation the exhaust, after passing through the DPF, encounters a deflection plate and is directed towards the rear of the machine. A section of convoluted flexible tubing complete with mating flanges was mounted between the engine manifold and the DPF inlet. The flexible tubing acted as a shock absorber reducing the stress between the engine manifold and DPF inlet. Easy removal of the DPF from the LHD was accomplished through the use of 4 hole mating flanges on the DPF exhaust inlet and outlet. DPFs could be removed from the LHD vehicle in approximately 10 minutes by the simple removal of sixteen 6 mm. bolts. The total length of time for initial retrofitting of the LHD with DPFs was a total of 2 working shifts (16 hours).

VEHICLE OPERATIONS

Engine exhaust manifold temperatures and RPM were constantly monitored during vehicle operations. Four modes of vehicle operation were identified:

1. Run to stope
The LHD vehicle travels from the ore pass to the mucking face at the stope.
2. Mucking
The LHD vehicle fills the bucket with ore.
3. Run to ore pass
The LHD vehicle travels from the stope to the ore pass with a load of ore.
4. Dump
The LHD vehicle dumps the bucket of ore down the mill hole (ore pass).

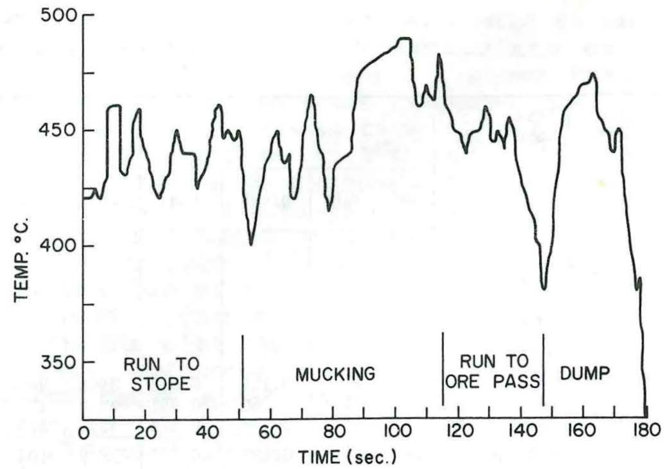

FIG. 4 KIDD CREEK LHD CYCLE TEMPERATURE.

TABLE 4

KIDD CREEK LHD CYCLE ANALYSIS

Condition	Time (sec)	RPM	Temp. (C)
Run to Stope	51	2071	439
Mucking	64	1841	443
Run to Ore Pass	30	2294	443
Dump	35	1320	430
Cycle Average	180	1880	439

The temperature profile recorded over the complete duty cycle is shown in Figure 4, while Table 4 shows an analysis of the average RPM and manifold temperatures experienced over each mode of the cycle, together with an overall cycle average, which was 1800 RPM, with an average temperature of 439°C. This is in excess of the light-off temperatures for particulate regeneration, for both the precious metal catalyst and fuel additive approaches, so that autoregeneration over this cycle may be expected.

In addition, on completion of each day's testing, the vehicle would climb an access ramp from the 915 metre level to the maintenance bay on the 853 metre

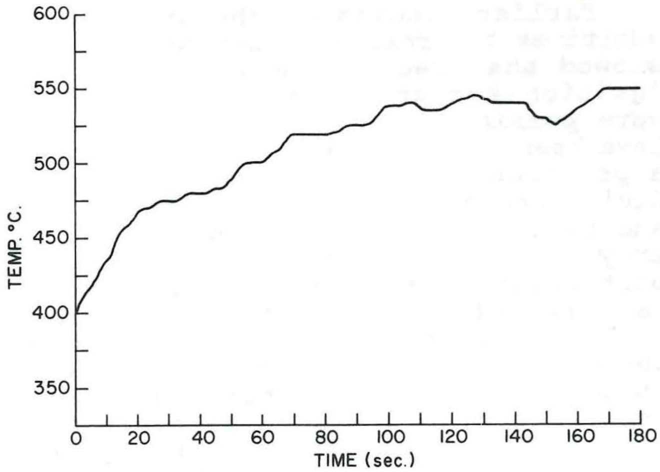

FIG.5 KIDD CREEK LHD RAMP ASCENT TEMP.

level. During one of these ramp ascents, the engine exhaust temperature and RPM were monitored.

Figure 5 shows the manifold exhaust temperatures recorded during the ascent. Such temperatures will also assist regeneration of the DPF at the end of each day.

DURABILITY TESTS AND REGENERATION EFFECTIVENESS

CATALYZED DPFs - Before installation of the DPF on the LHD machine, exhaust backpressures were recorded at idle, high idle, and during the ramp ascent, with the original exhaust system, which comprised a 6DM PTX catalyst and muffler. Both the PTX exhaust purifier and muffler were replaced with the ceramic DPF, since the mine operators felt subjectively that effective sound attenuation was achieved with the DPF alone. Table 5 shows the exhaust backpressures measured with the standard exhaust system. These data should be compared with Table 6 which shows lower exhaust backpressures when the original exhaust system is replaced with the ceramic DPF. In addition, during 250 hours of testing, the exhaust backpressures did not increase. Although filter regeneration was taking place at the end of each day with the ramp ascent, it was also noted that exhaust backpressures did not increase significantly during normal operations throughout the day. These operations included periods of idle (up to 30 minutes) and some light load operations where the vehicle was used for cleaning up small quantities of ore.

Qualitative observations by mines personnel associated with the test vehicle, attested to a marked reduction or absence of the typical visible soot or smoke emissions from the exhaust.

The catalyzed DPFs were therefore

TABLE 5

ENGINE EXHAUST BACKPRESSURES (KPA)
6DM PTX CATALYST + MUFFLER
ORIGINAL EXHAUST SYSTEM

Test	Bank	Idle	High Idle	Ramp
1	Right	4.0	6.0	7.0-8.0
	Left	4.5	6.5	7.0-8.0
2	Right	4.0	6.0	7.0-8.0
	Left	4.5	6.5	7.0-8.0
3	Right	3.8	6.5	7.0-8.0
	Left	4.2	6.2	7.0-8.0

TABLE 6

ENGINE EXHAUST BACKPRESSURES (KPA)
CATALYZED DPF'S
INSTALLED ON ST5 LHD VEHICLE

	Engine Hours	Bank	Idle	High Idle	Ramp
Prelim. Tests	770.0	Right	0.8	3.4	4.0
		Left	0.8	3.5	4.0
	777.9	Right	0.8	3.2	4.0
		Left	0.8	3.5	4.0
	791.7	Right	1.0	3.5	4.0
		Left	1.0	3.5	4.0
Endurance Tests	837.6	Right	1.0	3.4	****
		Left	1.0	3.4	****
	920.3	Right	0.4	2.5	****
		Left	0.4	2.5	****
	1055.7	Right	0.3	2.5	****
		Left	0.3	2.6	****
Total Hours 251.2					

operated a total of 251 hours on a vehicle engaged in mine production, in addition to 186 hours operation on the engine dynamometer test bed, for a total of 437 operating hours. During this period, no ceramic DPF failure was evident based on visual inspection of the DPF outlet. The structural integrity of the system for mine use has been demonstrated successfully over this period of time in actual mining operations.

FUEL ADDITIVES - Endurance testing in the mine was also carried out using an uncoated ceramic DPF and a fuel addi-

TABLE 7

ENGINE EXHAUST BACKPRESSURES (KPA)
STANDARD DIESEL PARTICULATE FILTER
INSTALLED ON ST5 LHD VEHICLE
WITH FUEL ADDITIVE

	Engine Hours	Bank	Idle	High Idle	Ramp
Prelim. Tests	803.1	Operated on Previous Shift			
	814.1	Right	0.8	0.8	1.5
		Left	0.8	0.8	1.5
	818.3	Right	0.4	2.4	2.0
		Left	0.4	0.8	2.0
	828.6	Right	0.3	2.5	2.5
		Left	0.3	0.8	2.5
Endurance Tests	1055.7	Right	0.3	2.5	****
		Left	0.3	2.5	****
	1215.0	Right	2.0	3.4	****
		Left	0.3	3.0	****
	1215.0	Right	0.4	3.0	****
		Left	0.3	3.0	****
Total Hours 193.8					

Note: The first pressure taken at 1215 was before ramp ascent. (The filter was coated with Diesel Fuel). The second time was after ramp ascent.

tive of 80 mg Mn/litre of diesel fuel. The fuel additive was supplied by Lubrizol Corporation, and blended into the diesel fuel in 45 gallon drum lots. Table 7 shows that, again, auto-regeneration was being achieved, and exhaust backpressures were satisfactory during the period of the trial. A total of 194 hours of endurance testing was achieved in mine use without filter failure.

During the fuel addtive mine field trials, however, three injectors on the right machine bank were found to be leaking unburnt fuel into the engine exhaust. Apparently the leaking diesel fuel coated the right DPF, increasing exhaust backpressure, and creating a power loss "mucking" and operation" problem. After replacement of the injectors, the DPFs were regenerated with an access ramp climb, which caused the right engine exhaust backpressure to decrease to the initial idle test conditions. The right DPF ceased smoking after the access ramp climb indicating the problem had been corrected.

SUMMARY AND CONCLUSIONS

Earlier studies on the use of fuel additives to promote filter regeneration showed that reductions in particulate ignition temperatures of up to 150°C were possible (4). Similar reductions have been found in the present study for a precious metal catalyzed DPF. This device enhanced regeneration potential, and resulted in good filtration efficiency for both insoluble and soluble particulate fractions (excluding sulfates). With the 0.25% sulfur diesel fuel used in the present study, however, 30-70% of sulfate was produced depending on the engine load factor and exhaust temperature. For vehicles exhibiting high load factors in their duty cycles, a selective catalyst could result in lower sulfate emissions while still allowing filter regeneration to take place. The sulfate emissions produced are not expected to be greater than those produced from precious metal catalyzed exhaust purifiers currently in mine use. The use of low sulfur fuel if needed, will also be beneficial in reducing sulfate emissions while maintaining good filter regeneration capability.

Both the ceramic DPF/fuel additive and catalyzed ceramic DPF systems survived and regenerated successfully on board an LHD mine vehicle for 251 total hours during routine vehicle operation at Kidd Creek Mine. Questions have been raised on the effects of manganese which might pass through the DPF (6). However, recent preliminary tests at this laboratory suggest that the retention of fuel additives on the ceramic DPF is very high.

Long term durability of the ceramic DPFs in the mine environment has yet to be established, and will be evaluated over the next two years. At this time, however, the ceramic DPF system appears to be viable in the real world of hard rock, non-gassy mine vehicle operations. Where vehicle load factors, and exhaust temperatures are very high, it may be possible to use ceramic DPFs without any regeneration assist. However, the use of catalyst coatings or fuel additives is recommended, tailored to the nature of the vehicle duty cycle, in order to reduce the risk of developing unacceptable exhaust backpressures resulting from high particulate loadings on the filter. The use of ceramic DPFs in gassy mines should be possible with development of appropriate insulation to reduce skin temperatures to acceptable limits, and a system to reduce the tailpipe exhaust temperature. It is also expected that the ceramic DPF will act as a flameproof device, but this needs to be established with appropriate testing.

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