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Evaluation of Diesel Particulate Exposures and Control Technology in a Nonmetal Mine

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ABSTRACT

The Mine Safety and Health Administration, in cooperation with IMC Global Operations, Inc., conducted a joint study to determine the effectiveness of the technology currently in use at the mine to control diesel particulate exposures.

IMC Global operates a potash mine using diesel-powered equipment to extract minerals from an underground mine. IMC uses a variety of technologies to control worker exposures to diesel particulate. These technologies include: ventilation, low sulfur fuel, oxidation catalytic converters (OCC), maintenance and work practices.

The study was conducted over a two week period, two shifts per day. During the first week (six shifts), baseline data on exposures and diesel particulate emissions were obtained. New OCC's were installed over the weekend on all equipment on the test section. During the second week (six shifts), data were collected to assess the effectiveness of the new OCC devices. In addition to exposure and diesel particulate emissions data, mine ventilation, engine exhaust temperatures and mine operational data were obtained.

The primary means of determining diesel particulate concentrations was the respirable combustible dust (RCD) method. Gas concentrations carbon monoxide (CO), carbon dioxide (CO_2), nitrogen dioxide (NO_2) were measured using passive dosimeter badges and gas bottles.

Results of measurements of diesel particulate, gases, and airflows were analyzed to determine the effectiveness of airflow and oxidation catalytic converters for controlling diesel particulate exposures. The use of oxidation catalytic converters

resulted in reductions of both workers exposures and diesel emissions.

INTRODUCTION

In cooperation with IMC Global, a diesel particulate study was conducted at a potash mine located near Carlsbad, New Mexico. This study was conducted as part of the Mine Safety and Health Administration's (MSHA) current program to assess diesel particulate in the mining industry. The purpose of this study was to evaluate the combined effectiveness of ventilation, maintenance, low sulfur fuel, oxidation catalytic converters (OCC), and work practices for controlling employee exposure to diesel particulate (Watts, 1995; Haney, 1995).

DESCRIPTION OF MINING OPERATION

The tests were conducted in an underground multilevel potash mine. The area of the mine where the diesel particulate study was conducted use a 17-entry room-and-pillar mining section. The section had two conveyor belt systems located nine entries apart for transport of ore. Entries were driven on 62-foot centers. Connecting crosscuts were driven on 72-foot centers. Room development proceeds from right to left across the panel. At the time of the study, approximately eight feet of ore was being mined.

Intake air available to the area where the test was conducted ranged from 115,000 to 139,000 cfm. The test area had three intake entries and 14 return (exhaust) entries. Two belt entries were separated by nylon brattice cloth. Airflow to the working faces was induced by auxiliary fans located in the last open crosscut. Auxiliary fans were also located near the belt feeder/breakers and at various other areas in the return entries.

This area utilized conventional mining methods and equipment including an electric-powered face drill, loading machine and undercutter and diesel-powered face haulage, roof bolting and utility vehicles. Faces were shot at lunch time and between shifts.

The production equipment included:

- Three 139 horsepower haulage vehicles,
- One 55 horsepower diesel roof bolter,
- One 55 horsepower lube or maintenance vehicle,
- One 27 horsepower ANFO wagon, and,
- One 55 horsepower man trip vehicle.

Three diesel vehicles were available for diesel face haulage. Only two of the vehicles were operated at one time. The typical production cycle had two vehicles being loaded by a loading machine with one haulage vehicle inactive as a spare. The diesel equipment had indirect injection engines.

All diesel vehicles were equipped with OCCs. The primary purpose of the converters was to reduce the carbon monoxide content in the vehicle exhaust. However, oxidation catalytic converters can also provide some reduction in the soluble organic fraction of the diesel particulate. Because the fuel being used previously contained sulfur, it is believed the old catalysts were coated with sulfate soot, reducing the temperature and the performance of the OCCs.

Prior to the study, the company had switched to using a low sulfur fuel. The use of low sulfur fuel reportedly improved visibility and reduced odors. An analysis of the fuel indicated a sulfur content less than 0.05 percent. To improve fuel lubricity, automatic transmission fluid was occasionally added to the fuel tanks.

The company operates an underground shop to rebuild and maintain diesel equipment. After an engine is rebuilt, it is placed on a dynamometer for breaking in and emissions testing. The engine is operated at various torque (load) and engine speed (RPM) settings for the break in period. Once the company is satisfied that the engine is working properly, the emissions are checked with stain tubes for oxides of nitrogen. After engines are placed in operation, they are serviced on a weekly basis or more often if the engine is smoking. Servicing includes changing the oil and air filters and checking the emissions with stain tubes for oxides of nitrogen.

TEST PROCEDURES and INSTRUMENTATION

This study was conducted during 12 production shifts. The first six shifts were surveyed to establish baseline diesel particulate personal exposures and area concentrations, along with associated ventilation and gaseous emission data. For these six shifts, the existing (old) OCCs remained on the equipment.

Following baseline testing, the OCCs on six vehicles were replaced on the maintenance shift. New converters were placed on three haulage vehicles, one lube vehicle, one roof bolter and the ANFO wagon. The OCCs on the man trips and section scoop were not replaced; however, these vehicles had minimal use during the study.

The second six shifts of data were collected after installing new OCCs on the diesel-powered production equipment. When the new OCC devices were utilized, engine exhaust temperatures were also monitored. Fuel samples and pertinent maintenance information was subsequently collected.

During the study, personal and area respirable particulate samples were collected and analyzed for combustible content using the respirable combustible dust (RCD) method (Haney, 1992). Personal samples were collected on five of the face occupations on each shift. These occupations included haulage vehicle operator, driller, loader, roof bolter, ANFO wagon operator, and section foreman. All personal samples were collected for the full shift.

Four area samples were collected per shift to determine diesel particulate emission rates. Since the mine utilized series airflow, one sample was collected in the main intake airway to the test area to determine the concentration of diesel particulate generated by upstream activity; one sample was collected in the intake near the end of the air walls and two samples were collected in the exhaust airflow. The area samples were operated while on section.

All samplers were calibrated at 1.7 Lpm. Samples were collected on 37 mm Silver Membrane filters with a 0.8 micrometer pore size. The filters were preconditioned by baking in a muffle furnace at 400^{o} C for one hour. The filters were pre- and post weighed to $\pm$0.001 milligram. After the dust samples were collected, the Silver Membrane filters were weighed and then again heated to a temperature of 400^{o} C for a minimum of one hour. After baking, the Silver Membrane filters were reweighed. The weight loss was considered diesel particulate.

Concentrations of diesel particulate levels were calculated by the following formula:

Concentration (time weighted average) =

$$\frac{\text{RCD Mass (mg)} \times 1000\ (\text{L/m}^3)}{1.7\ \text{Lpm} \times \text{Time (min.)}}$$

In addition to determining the airborne concentration of diesel particulate, samples were collected to determine the airborne concentrations of gaseous contaminants. Palm samples were used to determine the nitrogen dioxide (NO_2) concentration. NO_2 concentrations were determined by spectrophotometry. Vacuum bottle air samples were collected to determine the airborne concentrations of carbon dioxide (CO_2), and carbon monoxide (CO). Gas samples were collected each shift at the return sampling location. When on-shift blasting occurred, samplers were closed for approximately one hour to allow the gases from blasting to pass the sample location. Concentrations of CO_2, and CO were determined by gas chromatography.

In order to define the parameters associated with the operation of the OCCs, temperature traces of exhaust gases were made for three of the diesel vehicles. These vehicles included a haulage vehicle, the roof bolter, the lube vehicle and the ANFO wagon. A thermocouple was placed into the exhaust pipe through the port on the engine side of the catalytic converter. Exhaust gas temperature was monitored on each of the four pieces of equipment for two to four hours. The temperatures were recorded and stored every 10 seconds on a data logger. The data logger was later downloaded into a computer file for plotting and analysis.

RESULTS AND DISCUSSION

Table 1 presents the results of the average personal diesel particulate concentrations measured on face workers and at area sample locations. The concentrations are shown for the old and new OCCs. Also shown in the table are average return gas concentrations and area airflows.

The airflow was approximately the same for the entire test period. Based on a total section operational horsepower of 415, (does not include man trip or scoop) the intake airflow per horsepower was approximately 290 cfm/hp. As indicated in the table, the replacement of the OCCs had little effect on the airborne gas concentrations.

Results of average personal and area diesel particulate samples are shown in Figure 1. During the first six shifts, when the old catalytic converters were utilized, the average of the personal samples collected during these shifts is 0.42 mg/m^3 with a standard deviation of 0.14. During second six shifts, when the new catalytic converters were utilized, the average of the occupational samples was 0.32 mg/m^3 with standard deviation of 0.08. With the exception of the cutter operator, all workers had a reduction in exposure to diesel particulate after installation of the new catalytic converters. The standard deviation indicates a 25 to 33 percent variation in area occupational samples.

These values indicate a reduction of approximately 24 percent in the overall average of the occupational exposures after the change in converters. Because the area airflow did not change, the effect of replacing the OCCs on engine emissions was determined from taking the difference between the section exhaust measurements (correcting for intake diesel particulate). This analysis indicates that the new OCCs were providing an additional 27 percent reduction in diesel particulate emissions.

The section studied was ventilated in series with another mining area. As a result, the intake airflow of the studied section was the return from another section. The section intake contained approximately 0.15 mg/m^3 of diesel particulate. This concentration contributed approximately one-quarter to one-third of the diesel particulate measured in the area exhaust.

Figure 2 shows a typical plot of a temperature trace. The plot shown is for a haulage vehicle. This vehicle had the heaviest use. Table 2 gives the range, average and standard deviation of the temperatures for each of the three vehicles monitored.

Performance of the catalytic converter is related to temperature. The hotter the exhaust temperature, the more effective the converter. Previous (Waytulonis, 1992) testing has shown that to be effective for reducing diesel particulate and carbon monoxide, an OCC should have an operating temperature consistently over 200^{o} C. Based on the results of the temperature measurements, the haulage vehicles and possibly the roof bolter were operating at a temperature hot enough for the OCCs to contribute to the reduction of diesel particulate.

FINDINGS AND CONCLUSIONS

1. During the study, diesel particulate emissions were being controlled by a combination of ventilation, low sulfur fuel, maintenance, and oxidation catalytic converters.

2. Diesel particulate levels were measured with old and new oxidation catalytic converters installed. The average of the personal samples collected with old and new OCCs were 0.32 mg/m^3 and 0.42 mg/m^3, respectively.

3. Due to the use of series ventilation, the intake air contributed approximately one-quarter to one-third of the total diesel particulate exposure.

4. Exhaust temperatures measurements indicated that only the haulage vehicles were operating at a temperature where OCCs could contribute to diesel particulate reduction.

REFERENCES

"Diesel Particulate Exposures in Underground Mines," by Haney R.A., Mining Engineering, February, 1992.

"A Collaborative Research Project to Evaluate Diesel Emission Control," by Watts, W.F., Ellis, M.G., Haney, R.A., et. al., SME Annual Meeting, Preprint 95-128, Denver, CO, March, 1995.

"An Overview of Diesel Particulate Exposures and Control Technology in the U.S. Mining Industry," by Haney, R.A., Saseen, G.P., and Waytulonis, R.W., Proceedings of the 2nd International Conference on the Health of Miners, Pittsburgh, PA, November, 1995.

“Modern Diesel Emission Control”, by Waytulonis, R. W., Diesels in Underground Mines: Measurement and Control of Particulate Emissions, Proceedings of Bureau of Mines Information and Technology Transfer Seminar, Minneapolis, MN, September 29-30, 1992, Bureau of Mines IC 9324. Table 1 - Results of Personal and Area Diesel Particulate Samples Before and After Oxidation Catalytic Converter (OCC) Replacement.

Table 1. - Results of Diesel Particulate Study Before and After Oxidation Catalytic Converter (OCC) Replacement

OCCUPATION (mg/m³)	OLD OCC AVERAGE	NEW OCC AVERAGE
RAM CAR #1	0.38	0.36
RAM CAR #2	0.45	0.30
LOADER	0.53	0.30
CUTTER	0.25	0.28
DRILL	0.37	0.29
BOLTER	0.61	0.39
AVG. OCC.	0.42	0.32
STD. DEV.	0.14	0.08
AREA (mg/m³)		
MAIN INTAKE	0.11	0.13
SECTION INT.	0.14	0.15
RETURN #1	0.47	0.39
RETURN #2	0.49	0.39
INTAKE AIR (x 100,000 cfm)	121	120
RETURN GASES		
NO_2 (ppm)	0.25	0.27
CO (ppm)	6.17	4.63
CO_2 (%)	0.10	0.11
CH_4 (%)	0.00	0.00

Table 2. - Summary of temperature measurements on vehicles with replaced catalytic converters

	Minimum Degrees C	Maximum Degrees C	Average Degrees C	Standard Deviation Degrees C
RAMCAR	113	472	292	69
LUBE VEHICLE	97	273	151	21
ROOF BOLTER	44	304	211	48

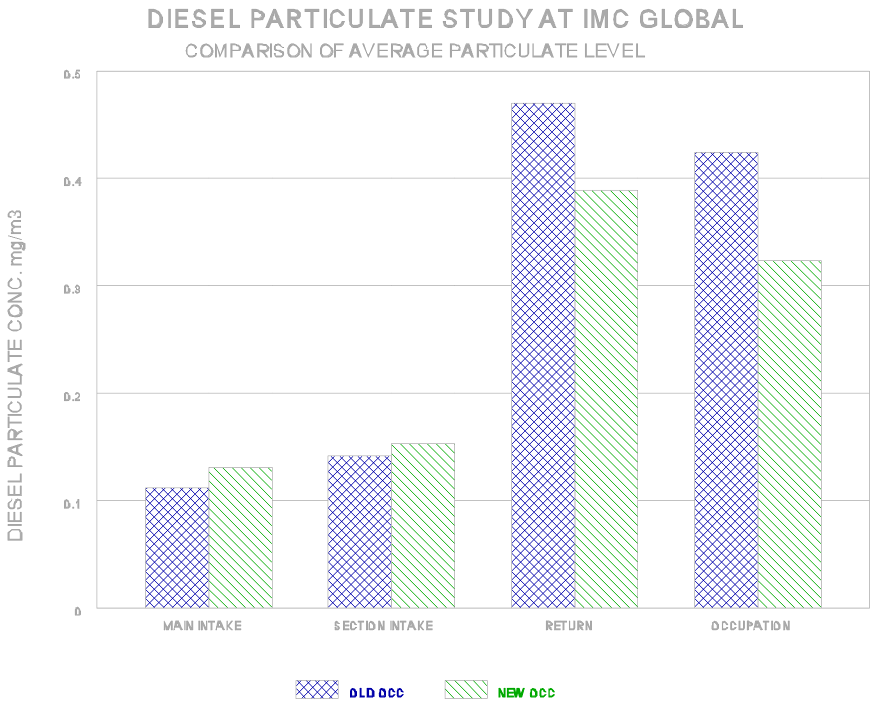

Figure 1. Average Area and Occupational Diesel Particulate Samples

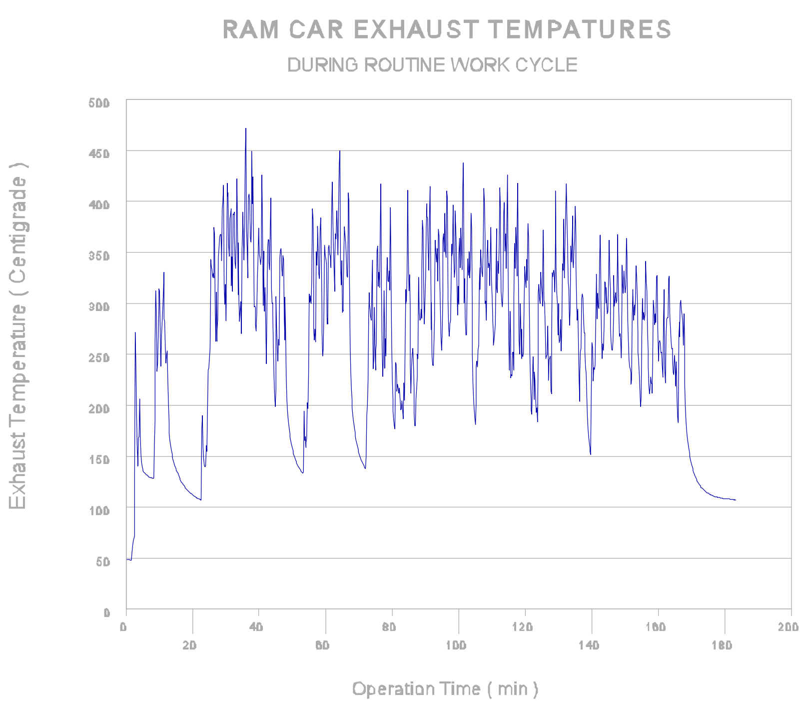

Figure 2. Temperature Trace - Haulage Vehicle