

**Report of Investigation Submitted to the
Diesel Emissions Evaluation Program (DEEP)**



**EVALUATION OF THE CONTRIBUTION OF LIGHT-DUTY VEHICLES TO
THE UNDERGROUND ATMOSPHERE DIESEL EMISSIONS BURDEN
PHASE II - FINAL REPORT**

November 2003

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With the kind collaboration of



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ABSTRACT

A series of in-mine field studies were performed to determine the relative contributions of light and heavy-duty vehicles to the underground diesel emissions burden in a metal mine. Based on these tests, a model of the Kidd Creek mine diesel fleet was developed. Light-duty vehicles were responsible for 47% of the underground diesel particulate matter (DPM) burden of the model fleet, while heavy-duty (HD) vehicles were responsible for 53%.

CANMET - Mining and Mineral Sciences Laboratories Report 2003-059(CR)

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1.0 INTRODUCTION

The aim of this work is to characterize diesel particulate matter (DPM) exhaust emissions from light-duty (LD) and heavy-duty (HD) vehicles in a metal mine and to estimate the relative contributions of both types of vehicles to the overall underground DPM burden. The work is divided into two distinct phases. This reports deals with results of the second and final phase.

Some of the issues that were examined as part of the Phase I include: mine selection and selection criteria, characterization of the mine's diesel fleet, duty cycle assessment method, raw exhaust DPM sampling issues and determination of the cross-section of the fleet to be tested during Phase II.

The Phase II field study was divided into two parts. Part one focused on measurement of DPM from seven heavy-duty vehicles including five production load haul dump (LHD) vehicles and two haulage trucks. Part two focused on measurement of DPM emissions from eight light-duty vehicles including three pickup trucks, two tractors and three utility vehicles.

2.0 BACKGROUND

DEEP is presently involved in two major field studies aimed at evaluating high-efficiency diesel filtration technology from the standpoint of their impact on the underground environment and their implementation in underground mines. These studies are primarily focusing on heavy-duty vehicles, although two light duty vehicles are tested as part of the study at INCO Stobie mine. The constantly increasing number of light duty vehicles in underground mines and limited knowledge on their contribution to overall diesel emissions motivated this study.

Data showing the relative contribution of light-duty vehicles to DPM concentrations in a test mine can be used to determine whether further research and work aimed at light-duty engine emissions are needed. The hypothesis is that enhanced efforts in emission control and maintenance aimed at the light-duty fleet may benefit the underground environment.

Traditionally, the size of the engine has been used to differentiate between light, and heavy-duty vehicles. In this study, vehicles that are not used in regular production cycles will be categorized as light-duty units regardless of horsepower. Higher horsepower units involved in ore, waste or fill handling will be considered heavy-duty vehicles. Because of the large size of the engines involved and the intensive nature of the work performed, underground diesel emissions are thought to originate mostly from heavy-duty production equipment. While heavy-duty vehicles are no doubt major contributors, new data suggests that light-duty vehicles could be responsible for a significant and possibly increasing portion of the airborne diesel emissions burden in the mining environment.

Please refer to LDV Project Proposal, LDV Project Phase I Report, and LDV Project Phase II Proposal for further details. Available at www.deep.org.

3.0 KIDD CREEK MINE DIESEL FLEET

The Kidd Creek Mine is a copper/zinc operation located in Timmins, Ontario. The orebody has been mined through three separate shafts known as the No.1, No. 2 and No. 3 mines. There is ramp access from the surface to all areas of the mine. Kidd Creek mined 2.2 million tones of ore in 2002.

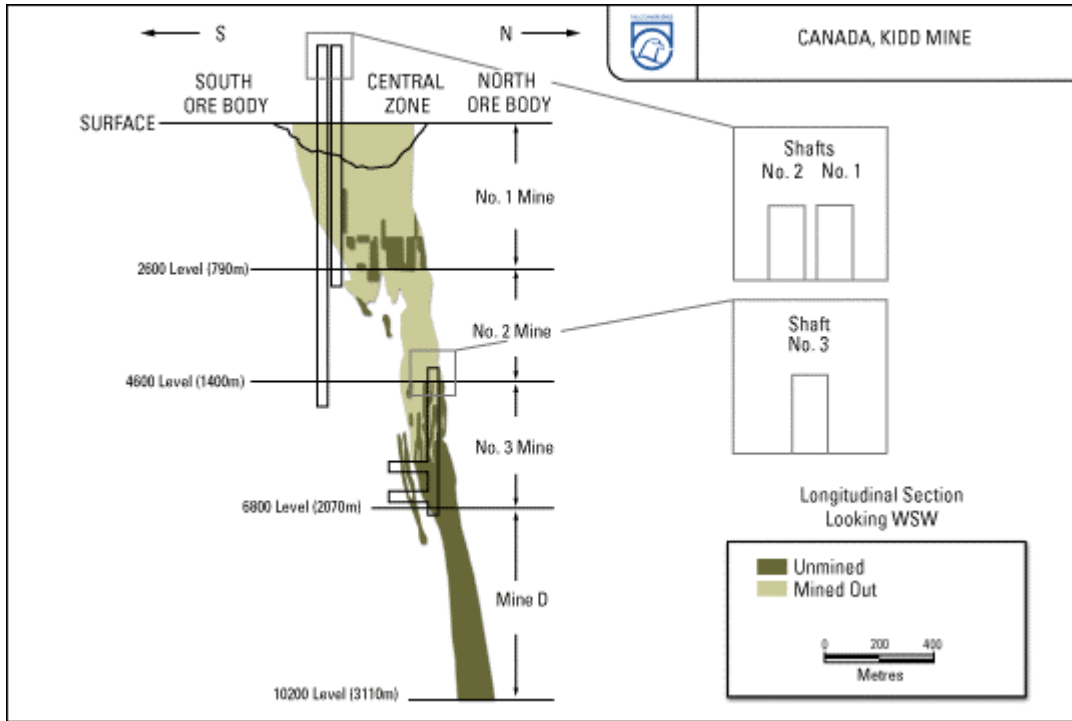


Figure 1: Kidd Creek Mine

The Kidd Creek diesel equipment fleet comprises approximately 156 vehicles used underground. The fleet was classified into two main groups; light-duty (LD) and heavy-duty (HD) vehicles. The HD group was further classified into two types: load haul dump (LHD) vehicles and haulage trucks. The LD group was further classified into three types: pickup trucks, tractors and utility vehicles.

Vehicle Type	Number
Load Haul Dump (LHD)	20
Haulage Trucks	2
Pickup Trucks U/G	42
Tractors	18
Utility Vehicles	74
Total U/G	156

Table 1: Breakdown of Kidd Creek U/G Diesel Fleet

It was technically feasible to test ten percent of the Kidd Creek Mine fleet, or 15 – 16 vehicles. The final selections were based on observation of the fleet, communications with mine staff and technical requirements. The following vehicles were selected.

Vehicle Type	Number
Load Haul Dump (LHD)	5
Haulage Trucks	2
Pickup Trucks U/G	3
Tractors	2
Utility Vehicles	3
Total U/G	15

Table 2: Vehicles Selected for the U/G Field Study

Part One Heavy-duty: the HD vehicle selections were made in the Phase I report. The reader is referred there for details. The vehicles tested were different from the original group selected because of availability problems, however the test vehicles are believed to be more representative of fleet operations.

Number	Vehicle ID	Task	Engine	Power (HP)
33635	SCOOPTRAM, TORO 501D	Stope Mucking LHD	Detroit Diesel Series 60, 11.1 L	285
33638	SCOOPTRAM, TORO 501D	Stope Mucking LHD	Detroit Diesel Series 60, 11.1 L	285
33638	SCOOPTRAM, TORO 501D (repeat)	Stope Mucking LHD	Detroit Diesel Series 60, 11.1 L	285
33616	SCOOPTRAM, TORO 400D	Stope Mucking LHD	Detroit Diesel Series 50, 8.5 L	250
33626	SCOOPTRAM, WAGNER ST3.5	Backfill Mobile Filling No. 1 Mine	Detroit Diesel 4-71, 4.65 L	180
33661	TRUCK, EJC430	Haulage Truck	Detroit Diesel Series 60, 11.1 L	300
33661	TRUCK, EJC430 (repeat)	Haulage Truck	Detroit Diesel Series 60, 11.1 L	300

Table 3: Heavy-Duty Vehicles Tested During the Field Study

The Toro 501D 8-yard LHD’s are used for main production. Unit 33635 was tested while operating on 4800 level (lower mine 3). Unit 33638 was operated on 2600 level (upper mine 1) and was tested twice, both times with mixed remote and manual control.

The Toro 400D 6-yard LHD is also used for production. Unit 33616 was tested operating from 28-2 sub level to 2600 level (upper mine 1).

The Wagner ST3.5 is used mainly for clean-up and backfill. Unit 33626 was tested operating on 44-1 sub level (upper mine 2).

The EJC430 haulage truck is used for main production. Unit 33661 was tested hauling ore from 7400 to 5100 and returning empty. Unit 33661 was tested again hauling from 7300 to 5800 level. The same truck was tested twice because the second requested truck was unavailable.

The following HD vehicle duty cycle matrix was obtained during testing:

Duty Cycle Description	LHD Size		
	3.5 yard	6 yard	8 yard
Heavy, single level, upper mine, remote			33638
Heavy, single level, lower mine			33635
Heavy, single level, upper mine, remote			33638 (R)
Medium, single level, upper mine	33626		
Medium, split levels, upper mine		33616	

Table 4: LHD Vehicle Test Matrix by Vehicle Unit Number

Part Two: Light-Duty: The LD vehicle selections were made after observation of the fleet and discussion with operators, supervisors and management. The following vehicles were selected as representative of the LD fleet.

Number	Vehicle ID	Task	Engine	Power (HP)
33348	TRUCK, CHEV 2500 [2000]	4600 Level Mobile Shop	General Motors L65 6.5L TD	195
33325	TRUCK, FORD SUPER DUTY [2002]	4600 Level Mobile Shop	Navistar 99F 7.3L TD	150 (250)
33336	TRUCK, DODGE RAM 2500 [2001]	Mine "D" Construction	Cummins ISB 5.9L TD	230
33966	TRACTOR, KUBOTA 5030	Ore & Waste Mobile Equipment No. 3 Mine	Kubota S20802-DI-A 2.8L	54
33952	TRACTOR, KUBOTA 5030	Construction Upper Mine No. 1	Kubota S20802-DI-A 2.8L	54
33973	SHOTCRETE, SPRAYER DRIFTEC	Lateral Development	Cummins QSB5.9-240 5.9L	240
33872	SCISSORLIFT, GETMAN A64	Supply & Sanitation	Deutz F5L413FRW 8.0L	110
33899	BOOM TRUCK, GETMAN A64	Construction Upper Mine No. 1	Deutz F6L912W 5.6L	82

Table 5: Light Duty Vehicles Tested During the Field Study

Unit 33348 is a Chevrolet 2500 pick-up mobile maintenance vehicle. It is used by mechanics to travel to disabled production equipment and return to the shop area after making repairs. It is also used to obtain supplies from the surface and to transport service personnel in and out of the mine. It operates anywhere required in the mine. Unit 33325 performs the same function, however it is a Ford Super Duty pick-up equipped with a 7.3L Powerstroke engine de-rated to an estimated 150 HP. Unit 33336 is a Dodge pick-up operated by the Mine "D" project. It is used to transport development personnel from the surface to Mine "D" (below 6800 level).

Unit 33966 is a Kubota 5030 tractor used by supervisory personnel to travel to various workings between 4600 and 6800 level (lower mine 3). Unit 33952 is an identical tractor used by construction personnel to travel to various construction and remediation projects in the upper mine 1.

Unit 33973 is a Driftec shotcrete sprayer. It uses diesel power to travel to working areas throughout the mine. Once at its designated work area, the diesel is shut down and the sprayer assembly is powered by electric motors.

Unit 33872 is a Getman scissor lift used to install piping and conduit in the mine. The diesel engine is used for traveling to work areas and for operating the hydraulic scissor lift.

Unit 33899 is a Getman flat bed articulated truck equipped with a hydraulically operated boom. It is used to transport material throughout the mine. The diesel engine is used to power the vehicle and hydraulic boom system.

These vehicles were selected to be representative of the Kidd Mine fleet. The only key vehicle missing from the trial was a jumbo drill rig. It was impossible to schedule a test for that type of vehicle because of production commitments. It may be possible to simulate drill rig operation from available test data as its duty cycle is similar to the Driftec shotcrete sprayer and it uses the same engine as the Getman boom truck.

4.0 TEST METHODOLOGY

This study focused on diesel particulate matter (DPM) emissions. No attempt was made to look at other gaseous emissions. In order to compare DPM emissions from LD and HD vehicles, it was necessary to monitor three major parameters; engine exhaust flow, DPM mass and duty cycle.

4.1 DPM Production Measurement

The ultimate goal of this study is to determine the amount of DPM produced by selected diesel powered vehicles over a specified sampling period and ultimately over a full-shift period. The following general formula can be used to illustrate:

$$M_{DPM} = C_{DPM} \times V_{EXH}$$

Where:

M_{DPM} = Mass of DPM (in milligrams) produced by the vehicle during the sampling period.

C_{DPM} = Concentration of DPM in exhaust as measured by the DPM sampling apparatus (milligrams per cubic meter at standard conditions) during the sampling period.

V_{EXH} = Total dry exhaust volume produced during the sampling period (cubic meters at standard conditions)

It is suggested that exhaust gas volume be used to classify light and heavy-duty vehicles. A vehicle that is performing significant work for the mine will be emitting a large volume of exhaust gas. In addition, because of the higher volumes produced, such vehicles have the potential to contaminate the mine workings more quickly.

4.2 Vehicle Duty Cycle Evaluation

Evaluation of each vehicle duty cycle will ensure that it is classified correctly as light or heavy-duty. It will also provide insight into the utilization for each vehicle and vehicle type.

All the HD, electronically controlled Detroit Diesel engines provide a percent engine load parameter on the ECU data stream. This data was recorded during each test. In addition, the shotcreter and pick-up truck were also equipped with electronically controlled engines.

Duty cycle data for mechanically controlled engines was determined based on engine rpm, exhaust flow, and temperature. Charts were prepared for each vehicle showing the duty cycle distribution. Further explanation of the measured parameters is contained in the Phase I report.

4.3 Testing Sequence

Each day the vehicle to be tested was brought to either the 4600 or 2800 level service shop. CANMET-MMSL personnel installed the DPM sampling system, dataloggers and ambient DPM and dust monitors. Each operator wore a personal sampling pump and train to measure personal exposure.

The vehicle would then proceed to its normal working area. CANMET-MMSL personnel would ride along with the operator to periodically change sample filters and make notes pertaining to the duty cycle. If no seats were available, (such as on the LHD and haulage trucks) personnel would follow in a pick-up truck chase vehicle.

The test vehicle would perform its normal duties during the shift. The cycle would be interrupted briefly (1-2 minutes) to change the DPM sample filter as required. After a sufficient number of duty cycles were recorded, the vehicle would return to the shop area where the sampling system was removed in preparation for the next shift.

All the HD vehicles were tested over a two-week period. The DPM system was then returned to CANMET-MMSL for recalibration for the LD vehicles. The LD vehicles were tested a few months later.

5.0 SAMPLING SYSTEM CONSTRUCTION

Preliminary DPM sampling system construction is explained in the Phase I report. After the release of that report, it was decided to modify the system for proportional flow. A control loop was integrated into the DPM sampling system to provide isokinetic sampling flow.

This is achieved by measuring the exhaust flow and temperature. As exhaust mass flow increases, the DPM sampling pump flow is increased proportionally. DPM mass collected on the sample filter is therefore weighted proportionally to the engine operating modes. The system has a fast response and calibrates well against laboratory instruments.



Figure 2: DPM Sampling System Installed on Wagner ST3.5 LHD

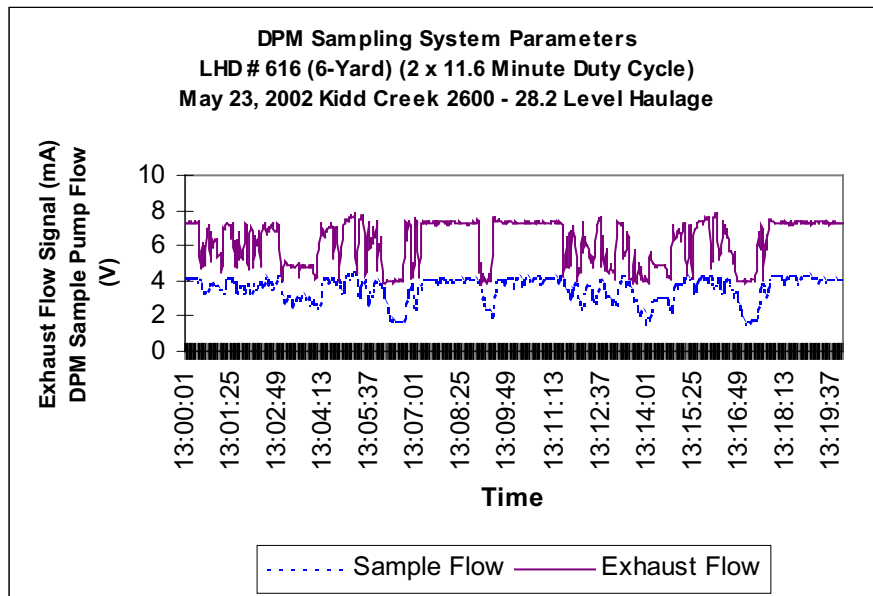


Figure 3: DPM Sampling System Response

The sampling system uses a series of interchangeable, averaging pitot tubes that allow exhaust flow feedback control for the complete range of vehicles tested at the Kidd Creek Mine. Each pitot tube was individually calibrated against laboratory instruments at the CANMET-MMSL Diesel Emissions test facility before use underground.

6.0 HEAVY-DUTY VEHICLE TESTING

6.1 Load Haul Dump (LHD) Vehicles

LHD # 33635 Toro 501D

This LHD is used for normal production on 4800 Level. The duty cycle is high torque and of approximately five minutes duration.

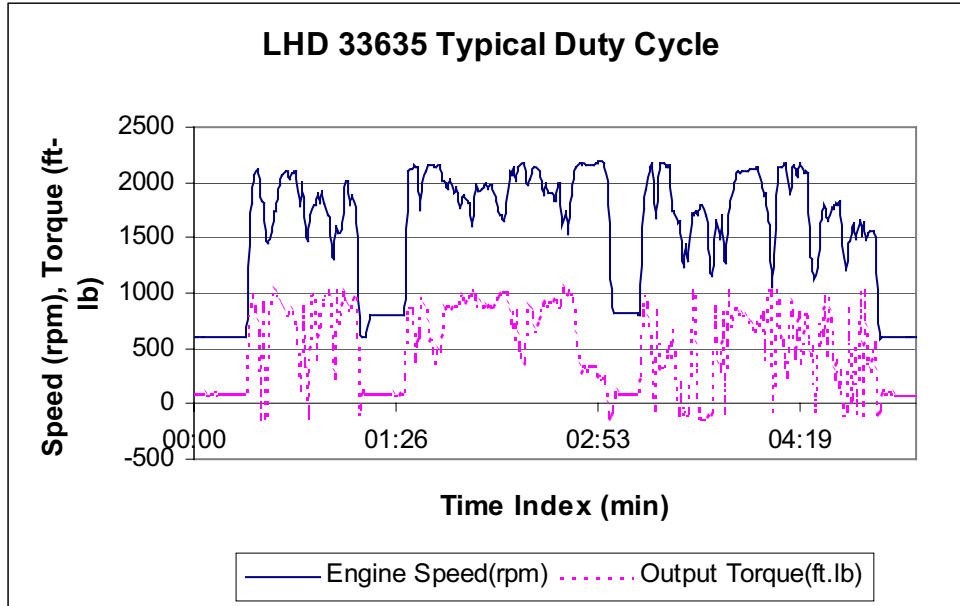


Figure 4: LHD 33635 Typical Duty Cycle

Vehicle	Duty Cycle Description	DPM (mg/m ³)	DPM Mass (g)	Run Time(min)	DPM Mass Rate(g/hr)
LHD 33635	4600 fuel bay to 4800	12.22	1.86	10	11.13
	Mucking on 4800	17.26	6.69	23	17.45
	Mucking on 4800	16.34	9.75	24	24.37
	Mucking on 4800	25.15	7.72	16	28.96
	Mucking on 4800	15.19	6.16	17	21.73
	Mucking on 4800	24.21	7.90	15	31.59
	Mucking on 4800	15.33	5.74	20	17.23
	Up ramp 4800 to 4600S	N/A	N/A	N/A	N/A

Table 6: LHD 33635 DPM Emission Summary

The field exhaust DPM concentrations are consistent with laboratory data obtained from a similar engine. The DPM mass emission rate while mucking can be three times higher than when traveling to the work area because of transients.

LHD # 33616 Toro 400D

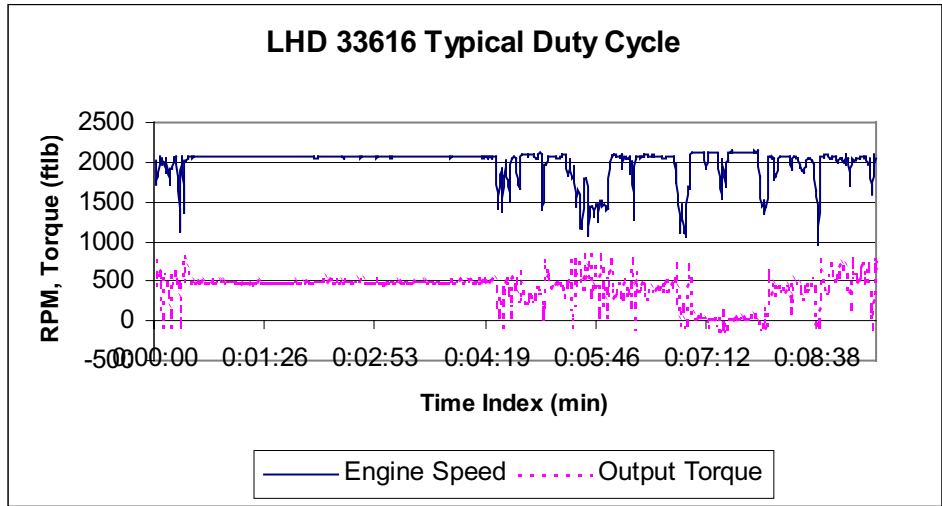


Figure 5: LHD 33616 Typical Duty Cycle

LHD 33616 has a duty cycle where the draw and dump points are on different levels. The haul up ramp section can be clearly seen on the above chart ending at approximately 04:19. The length of time to travel up the ramp loaded can be compared to the time it takes to descend the ramp at approximately 07:12.

Vehicle	Duty Cycle Description	DPM (mg/m ³)	DPM Mass (g)	Run Time(min)	DPM Mass Rate(g/hr)
LHD 33616	4800 to 3000 (traffic)	15.90	7.54	36	12.56
	3000 to 2800	14.72	7.98	37	12.94
	Turned on vent fan	29.29	4.15	19	13.11
	Mucking 28-2 to 2600	26.47	3.71	11	20.23
	Mucking 28-2 to 2600	23.88	3.44	10	20.64
	Mucking 28-2 to 2600	21.08	3.36	12	16.80
	Mucking 28-2 to 2600	22.86	3.27	11	17.83
	Mucking 28-2 to 2600	24.55	3.43	10	20.60
	Mucking 28-2 to 2600	25.01	3.33	10	19.98
	No muck	20.12	3.00	10	17.98

Table 7: LHD 33616 DPM Emission Summary

LHD 33616 has a duty cycle twice as long as 33635 because of the split level mucking. The mass emission rate is slightly lower than 33635 likely because the ramp travel allows steady state engine operation over a significant portion of the cycle. Such steady state conditions promote good exhaust quality.

LHD #33626 Wagner ST 3.5

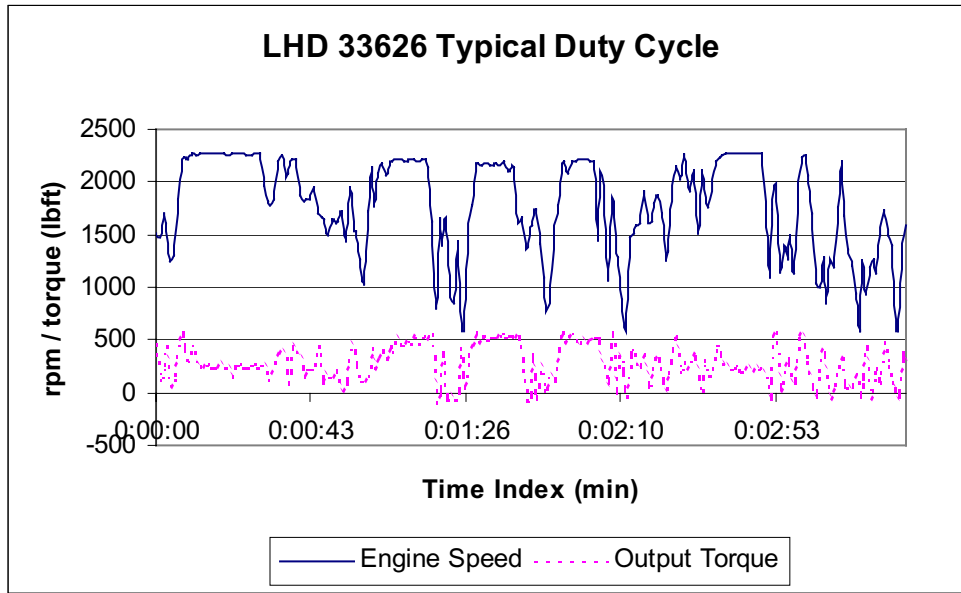


Figure 6: LHD 33626 Typical Duty Cycle

Vehicle	Duty Cycle Description	DPM (mg/m ³)	DPM Mass (g)	Run Time(min)	DPM Mass Rate(g/hr)
LHD 33626	4600S to 44-1	44.41	10.29	10	61.73
	Mucking on 44-1 (3 cyc)	27.96	4.29	9	28.61
	Mucking on 44-1 (2 cyc)	23.18	3.75	9	25.00
	Mucking on 44-1	15.79	3.06	10	18.37
	Mucking on 44-1	14.81	3.59	12	17.96
	Mucking on 44-1	18.14	2.59	8	19.44
	Mucking on 44-1	13.93	2.37	9	15.77
	Mucking on 44-1	18.00	3.29	10	19.73
	Mucking on 44-1	19.35	3.57	12	17.83
	44-1 to 4600S	20.25	1.01	7	8.69

Table 8: LHD 33626 DPM Emission Summary

The Series 60 and 50 engines emitted more DPM during the transient portions of the cycle and less during steady state. However, the Series 71 engines emitted more DPM during steady state.

LHD # 33638 Toro 501D

Unit 33638 is identical to 33635. This LHD is equipped with a remote control system and DPM sampling was done over a mix of manual and remote operation. The data for unit 33638 is a composite of two separate tests performed two days apart due to sampling equipment problems.

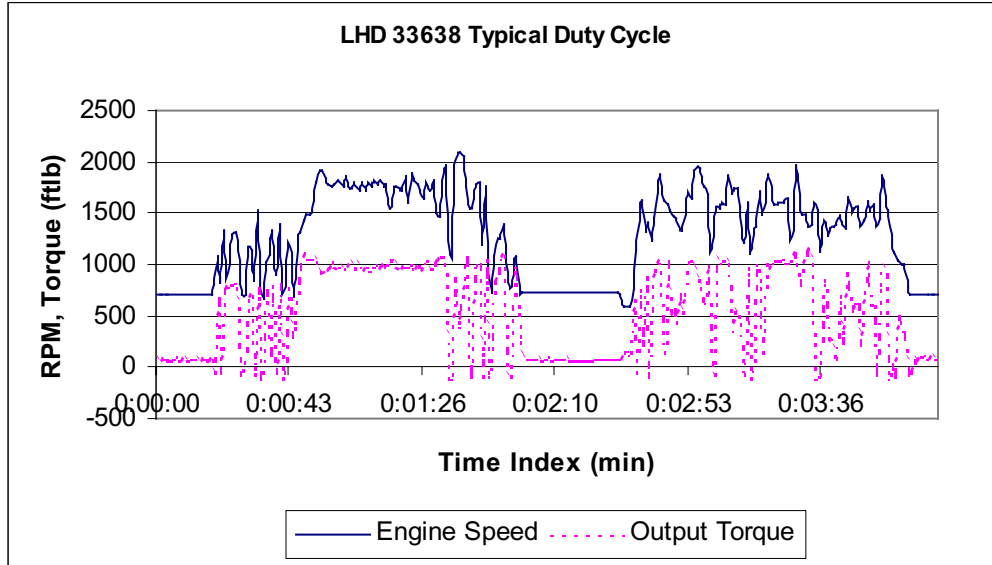


Figure 7: LHD 33638 Typical Duty Cycle

The duty cycle for LHD 33638 is split into two sections. The first section (0:18 to 2:00) is the manual tramming and dumping operation. At 2:00, the operator idles the LHD, disembarks and retreats a safe distance to engage the remote control system. The second section (2:30 to 4:00) represents the remote cycle as the LHD approaches the drawpoint, crowds the pile, loads and returns to the operator.

Vehicle	Duty Cycle Description	DPM (mg/m ³)	DPM Mass (g)	Run Time(min)	DPM Mass Rate(g/hr)
LHD 33638	2800 to 2500 to 2600	16.36	6.17	24	15.44
	Mucking on 2600 (3cyc)	12.58	3.70	13	17.06
	Mucking on 2600 (3cyc)	13.43	3.24	12	16.20
	Mucking on 2600 (2cyc)	12.87	2.37	10	14.23
	Drawing on 2600	43.36	2.14	4	32.11
	Dumping on 2600	22.04	0.59	1	35.33
	Mucking on 2600 (3cyc)	30.99	6.35	9	42.31
	Mucking on 2600 (2cyc)	28.94	7.47	11	40.74
	Mucking on 2600 (2cyc)	19.79	4.83	12	24.14
	Mucking on 2600 (2cyc)	20.16	5.14	13	23.74
	2600 to 2800S	13.59	1.08	8	8.07

Table 9: LHD 33638 DPM Emission Summary

6.2 Haulage Trucks

Truck # 33661 (And # 33661 Repeat)

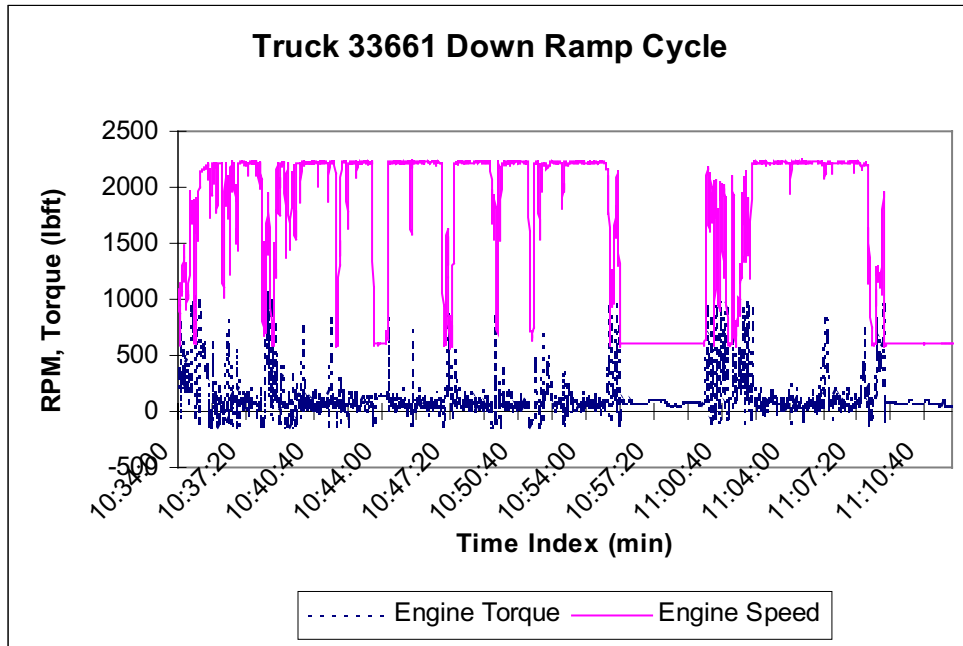


Figure 8: Truck 33661 Down Ramp Cycle

When descending the ramp empty, the haulage truck engine speed is high, while the developed torque is low. Since the ramp is not wide enough for two-way traffic, the truck must stop repeatedly to allow smaller vehicles time to reverse and clear the way. This is reflected by short idle periods in the chart. Occasionally, if convenient, the truck will reverse and yield.

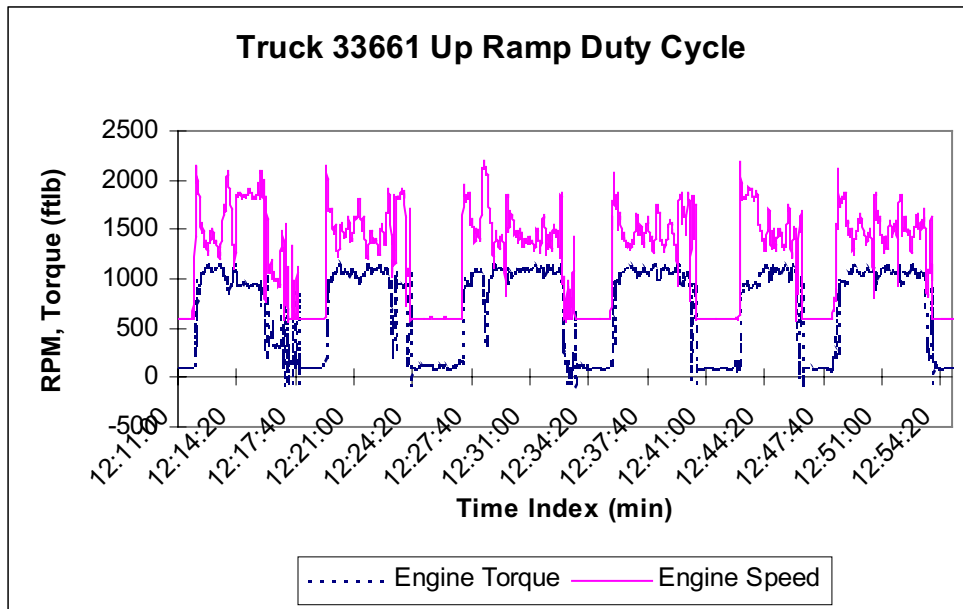


Figure 9: Truck 33661 Up Ramp Cycle

The engine operating near the peak torque point characterizes the up ramp cycle. The idle sections are where personnel were exchanging DPM filters.

Vehicle	Duty Cycle Description	DPM (mg/m ³)	DPM Mass (g)	Run Time(min)	DPM Mass Rate(g/hr)
Truck 33661	4600S to 6400	28.13	14.68	24	36.71
	6400 to 6900	25.10	5.74	12	28.70
	Idle on 6900	12.77	0.36	5	4.33
	6900 to 7400	25.11	9.38	19	29.63
	7400 to 7200	18.51	3.79	8	28.43
	7200 to 7000	10.34	1.43	6	14.26
	7000 to 6900	11.30	2.46	8	18.46
	6900 to 6600	11.18	1.77	6	17.70
	6600 to 6400	3.68	0.66	7	5.62
	6400 to 6200	2.59	0.47	8	3.49
	6200 to 5800	7.89	1.68	8	12.60
	5800 to 5600	5.91	1.08	8	8.08
	5600 to 5400	5.57	0.73	5	8.70
	5400 to 5200	4.61	0.89	7	7.64
	5200 to 5100	10.09	1.93	9	12.85
	5100 to 4600S	9.37	3.40	12	17.01

Table 10: Truck 33661 DPM Emission Summary

The truck operation modes are best defined as descending the ramp empty, idling, and hauling up the ramp loaded. The lowest DPM production rate occurs at the idle mode.

It was initially thought that the descending ramp mode would also have a low DPM emission rate due to the fuel being shut off under compression braking. The field trials have shown that, contrary to this theory, the engine is still developing power as the operator attempts to maintain a vehicle speed consistent with production goals.

This places the engine in a high speed / low torque mode where combustion temperatures are low leading to poor in-cylinder DPM control and higher emissions. In addition, the turbocharger boost pressures at that operating mode are not elevated enough for efficient combustion.

Once the truck has been loaded and is ascending the ramp, the engine can achieve steady state operating conditions, and relative low DPM emissions.

7.0 LIGHT-DUTY VEHICLES

7.1 Pickup Trucks

All three pick up trucks had a similar duty cycle, serving mainly as personnel and light material transport through the mine. Kidd Mine currently uses pick up trucks supplied by three major manufacturers; Chevrolet, Ford and Dodge.

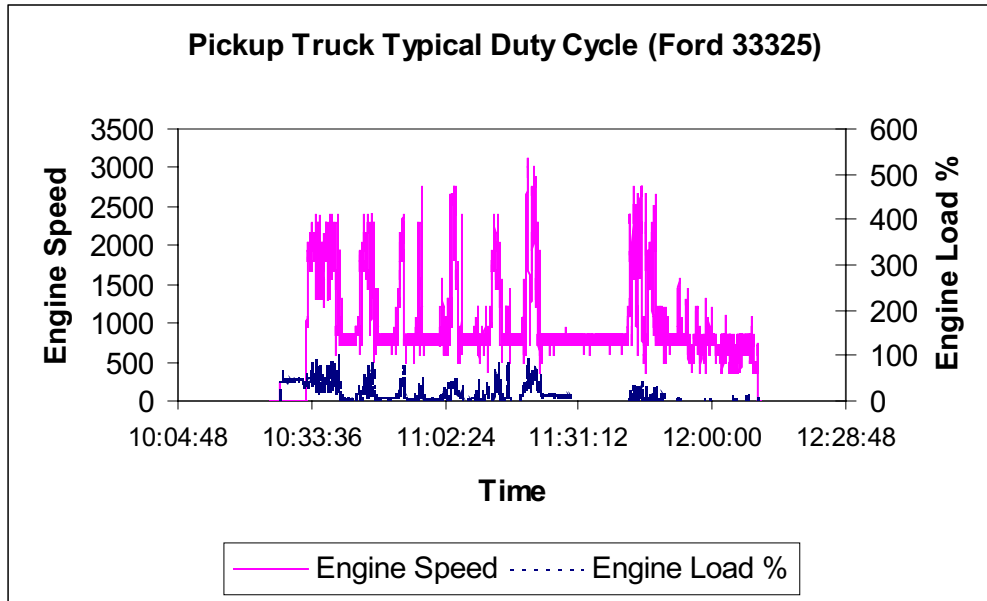


Figure10: Pickup Truck Typical Duty Cycle (Ford 33325)

All the pick ups have a large percentage of idle time due to the nature of their work. In addition, average engine load is 10 to 15%. There are no areas where sustained high power is required. Even when ascending the ramp, the pickups have so much extra power that it is possible to quickly exceed recommended maximum ramp travel speeds.

The pickup trucks are inefficient because the mine must still provide ventilation for the engine rated power according to regulations even though it almost impossible to apply that power towards useful work. The trucks do have the advantage of high speed transport through the mine and relatively low DPM emission rate due to their lightly loaded duty cycles.

Vehicle	Duty Cycle Description	DPM (mg/m ³)	DPM Mass (g)	Run Time(min)	DPM Mass Rate(g/hr)
Chevrolet	4600S to 4000	16.54	0.86	10	5.18
33348	4000 to 34-2 (traffic)	17.96	1.28	12	6.38
	34-2 to 2800	16.11	0.75	6	7.47

	2800 to 34-2	N/A	N/A	N/A	N/A
	34-2 to 38-1	N/A	N/A	N/A	N/A
	38-1 to 42-1	N/A	N/A	N/A	N/A
	Idle on 42-1	6.35	0.25	19	0.80
	42-1 to 4600S (traffic)	9.24	0.29	8	2.17
	4600 Level run	12.24	0.61	18	2.04

Table 11: Chevrolet Pickup #33348 DPM Emission Summary

Unfortunately, some DPM data was lost for #33348, however enough was saved to characterize DPM emissions from the four common modes of operation. Those modes are: ascending the ramp, descending the ramp, idling, and running on a level.

The idle mode has the lowest DPM mass emissions, ascending the ramp has the highest followed by descending and running on a level. While descending the ramp, the pickup trucks exhibited similar behavior as the HD haulage trucks. It was anticipated that ramp descent would yield the lowest DPM emission rate because of fuel shut off during compression braking. Instead, because of the limited number of transmission ratios available, compression braking in first gear results in too slow a descent.

Shifting to a higher gear increases the vehicle speed to a dangerous level. The operator is then forced to alternately brake and accelerate down the ramp to achieve an acceptable rate of descent, consistent with local ramp conditions. Use of the accelerator pedal injects fuel into the engine, which cannot be burned effectively due to the low in-cylinder temperatures and lack of turbo boost.

Vehicle	Duty Cycle Description	DPM (mg/m ³)	DPM Mass (g)	Run Time(min)	DPM Mass Rate(g/hr)
Ford Pickup	4600S to 36-3	9.19	0.76	13	3.50
33325	36-3 to 2800S	3.67	0.16	8	1.22
	2800S to 28-7 to 2800S	6.54	0.19	9	1.26
	2800S to 36-3	3.62	0.12	8	0.91
	36-3 to 2800S	8.49	0.43	11	2.33
	2800S to 36-3	8.31	0.29	6	2.90
	Idle on 36-3	4.20	0.10	16	0.37
	36-3 to 4600	3.30	0.17	11	0.93
	4600 Level run	9.38	0.36	17	1.26

Table 12: Ford Pickup # 33325 DPM Emission Summary

The Ford pickup has a similar modal DPM emissions breakdown as the Chevrolet. The Ford truck was de-rated to approximately 150 HP with an aftermarket device that modifies the demand signal sent to the electronic fuel injection system. The device is effective in reducing the DPM mass emission

rates. The Ford had the lowest DPM emission rates (per mode) of any vehicle tested.

Vehicle	Duty Cycle Description	DPM (mg/m ³)	DPM Mass (g)	Run Time(min)	DPM Mass Rate(g/hr)
Dodge Pickup	4600 to 5600	N/A	N/A	N/A	N/A
33336	5600 to 4600	9.84	1.05	13	4.84
	4600 to 5600	N/A	N/A	N/A	N/A
	5600 to 4600	7.78	0.84	12	4.20
	4600 to 6800	2.09	0.15	22	0.41
	6800 to 4600	10.16	0.79	20	2.37
	4600 level run	22.88	1.47	17	5.18
	4600 idle	N/A	N/A	N/A	N/A

Table 13: Dodge Pickup # 33336 DPM Emission Summary

The Dodge pickup had the highest DPM emission rate during operation on the level. This is likely because of excellent performance on the up ramp modes. Unlike the engines used in the Ford and Chevrolet, the Cummins ISB engine used by Dodge develops rated power and peak torque at lower engine speeds.

The transmission gear ratios can thus be selected to provide the operator with a more useable range of vehicle speeds. The engine can be operated longer at sustained load, which improves DPM emissions.

Based on the available data, it is possible to rank the pickup trucks in order of best DPM emissions as Ford first, Dodge second and Chevrolet third. However, it should be noted that only one vehicle of each type was tested. More pickups should be tested over a longer period of time to develop a more sound opinion. In addition, the effect of the deration device on the Ford pick up should be further examined, perhaps looking at gaseous emissions also.

Finally, the Kidd Mine has started purchasing new Chevrolet pickups equipped with the 6.6L Duramax 6600 engine. This engine is rated at 300 HP, over 35% more power that the L65 engine it replaces. This vehicle should be tested also.

7.2 Tractors

The Kidd Mine uses tractors for personnel and light material transport also. Due to their slower speed, they are not often used as transport to and from the surface. They are used primarily to access areas where drift conditions preclude the use of pickup trucks.

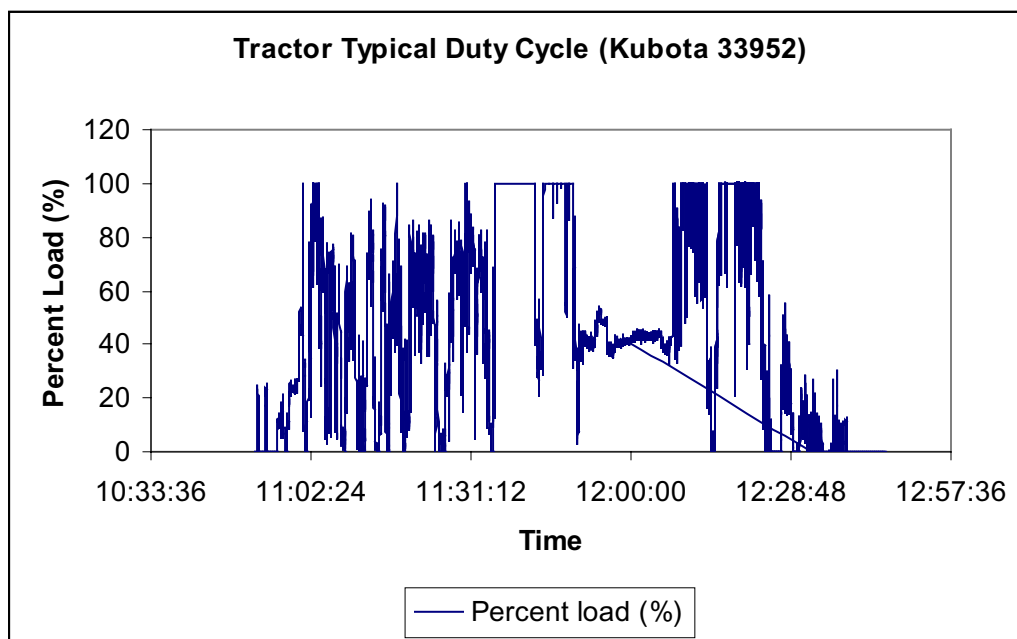


Figure 11: Tractor Typical Duty Cycle (Kubota 33952)

From 11:10 to 11:33, the tractor is descending the ramp. This is a highly transient mode of operation. The tractor has no suspension system and must be slowed when ramp conditions deteriorate and then accelerated back up to speed. Due to the effective gearing, the tractor can be operated at steady state conditions during the ramp ascent. The Kubota tractors typically have a higher power utilization averaging 45 – 50%.

Vehicle	Duty Cycle Description	DPM (mg/m ³)	DPM Mass (g)	Run Time(min)	DPM Mass Rate(g/hr)
Kubota Tractor	5100 to 5400	34.59	0.89	8	6.68
33952	5400 to 5800	31.73	0.85	7	7.26
	5800 to 6400	30.64	0.93	8	6.97
	6400 to 5800	105.56	5.40	8	40.53
	5800 to 5400	64.90	2.90	7	24.82
	Idle on 5400	9.74	0.29	15	1.14
	5400 to 5100	68.48	2.73	7	23.38
	4600 level run	36.39	2.21	13	10.21

Table 14: Kubota Tractor # 33952 DPM Emission Summary

The Kubota tractor is powered by an older, mechanically controlled engine. It is not turbocharged and uses old style pencil-type injectors. As a result the DPM mass emission rates at high engine loads are greater than for either the 8-yard LHD or the 30 ton haulage truck.

Vehicle	Duty Cycle Description	DPM (mg/m ³)	DPM Mass (g)	Run Time(min)	DPM Mass Rate(g/hr)
Kubota Tractor 33966	4600S to 4700	129.97	2.02	4	30.27
	4700 to 4900	22.17	0.55	6	5.47
	4900 to 5100	53.64	0.78	4	11.71
	5100 to 5300	27.70	0.42	4	6.37
	5300 to 5100	253.16	5.26	4	78.95
	5100 to 4900	254.02	1.48	2	44.33
	4900 to 4700	156.34	3.21	4	48.20
	4700 to 44-1	156.69	5.27	6	52.68
	Idle on 44-1 (loping idle)	12.49	0.33	15	1.30
	44-1 to 4600	36.29	0.85	5	10.20
	4600 Level run	68.83	4.37	11	23.86

Table 15: Kubota Tractor # 33966 DPM Emission Summary

Kubota tractor 33966 had high DPM mass emissions including the highest value recorded during the study of 79 grams per hour. It is suspected that the fuel injection pump and governor assembly was out of adjustment on this vehicle, possibly contributing to the unexpectedly high emissions.

7.3 Shotcrete Sprayer

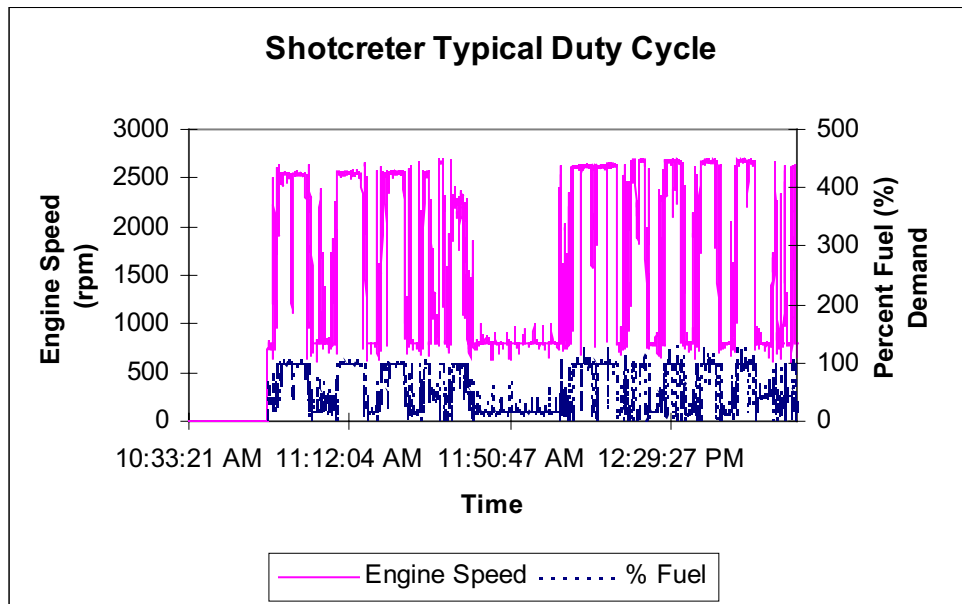


Figure 12: Shotcreter # 33973 Typical Duty Cycle

The Driftec Shotcrete sprayer is a very heavy vehicle. As a result the engine is at full power whenever the vehicle is traveling through the mine. However, once at the work area, the engine is completely shut down while shotcrete spraying operations are powered by 600V trailing cable.

While the engine is operating, the power utilization is the best of the light-duty vehicles, approaching 50%. This generates a tighter spread of DPM mass emission rates shown below.

Vehicle	Duty Cycle Description	DPM (mg/m ³)	DPM Mass (g)	Run Time(min)	DPM Mass Rate(g/hr)
Shotcreter	2800S to 2600	29.15	2.67	11	14.56
33973	2600 to 2400	12.38	1.70	13	7.84
	2400 to 2200	4.36	0.77	11	4.19
	2200 to 2300 to 2000 (tfc)	9.15	1.31	15	5.26
	Idle on 2000	2.40	0.50	17	1.78
	2000 level run (2 cyc)	8.81	1.96	16	7.35
	2000 to 2200	N/A	N/A	N/A	N/A
	2200 to 2400	4.34	0.51	8	3.79
	2400 to 2600	10.06	1.16	9	7.74
	2600 to 2800S	8.11	1.80	17	6.35

Table 16: Driftec Shotcrete Sprayer # 33973 DPM Emissions Summary

7.4 Scissor Lift

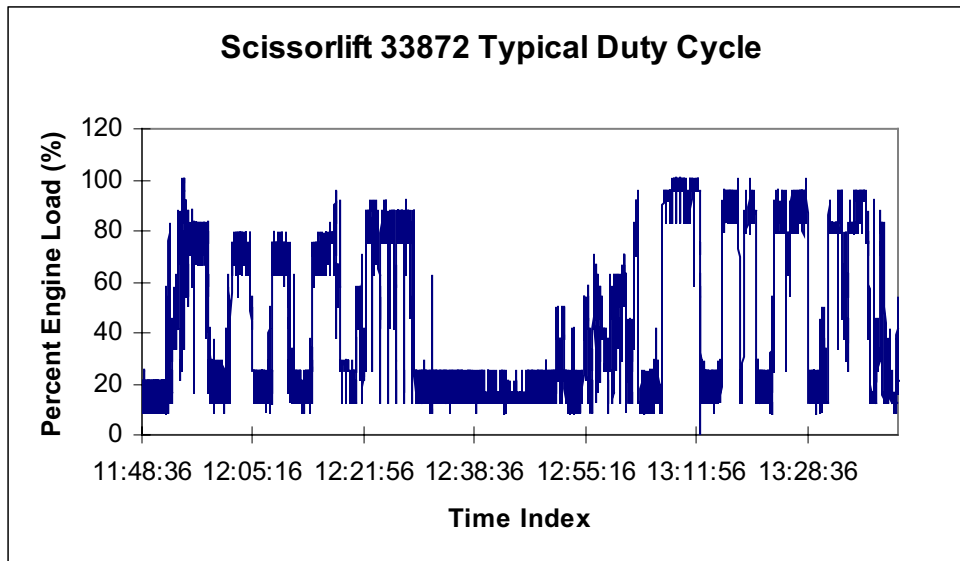


Figure 13: Scissor lift # 33872 Typical Duty Cycle

The scissor lift is used to install piping and conduit in the mine. The diesel engine is used for traveling to work areas and for operating the hydraulic scissor lift. This unit also has a relatively high average power utilization of 45%.

Vehicle	Duty Cycle Description	DPM (mg/m ³)	DPM Mass (g)	Run Time(min)	DPM Mass Rate(g/hr)
Scissor	4600S to 4800	10.19	0.67	8	5.03
33872	4800 to 5100	7.89	0.28	5	3.40
	5100 to 5300	10.46	0.57	7	4.86
	5300 to 5600	13.83	0.79	7	6.79
	5600 level run	18.88	1.92	10	11.52
	Idle on 5600	5.28	0.28	18	0.92
	5600 level lift operation	5.46	0.47	15	1.90
	5600 to 5300	15.39	1.35	9	8.98
	5300 to 5100	16.46	1.18	8	8.88
	5100 to 4800	20.51	1.41	7	12.06
	4800 to 4600S (some idle)	16.43	1.84	13	8.48

Table 17: Scissor Lift # 33872 DPM Emission Summary

The scissor lift has the highest DPM emissions while ascending the ramp. The scissor lift uses a Deutz 413W series indirect injection engine. The indirect injection combustion process has been shown to generate less DPM than the direct injection process (for naturally aspirated engines only). This is reflected in the field data by comparison with the DI Kubota tractors.

7.5 Boom Truck

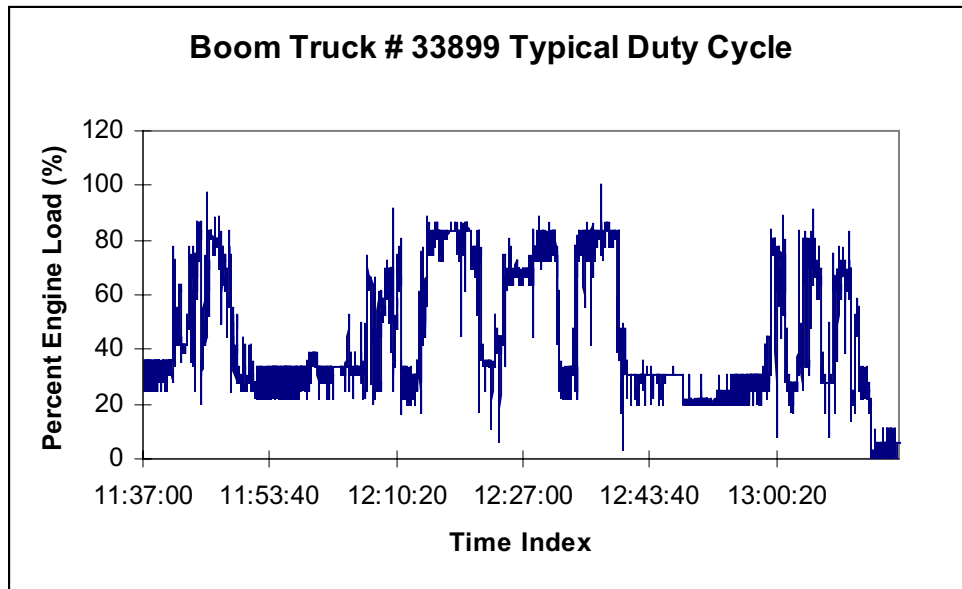


Figure 14: Boom Truck # 33899 Typical Duty Cycle

The boom truck is a utility vehicle that transports material throughout the mine. It spends most of its time on the ramp and the rest of the time loading and unloading.

Vehicle	Duty Cycle Description	DPM (mg/m ³)	DPM Mass (g)	Run Time(min)	DPM Mass Rate(g/hr)
Boom Truck	2800S to Station / lift	18.36	6.34	31	12.27
33899	2800 to 2600	23.59	4.29	11	23.41
	2600 to 2400	24.53	3.27	9	21.81
	2400 to 2200	16.70	2.48	9	16.51
	2200 idle	8.87	1.15	16	4.29
	2200 to 2400	13.86	0.79	5	9.51
	2400 to 2600	11.54	0.56	4	8.42
	2600 to 2800S	8.25	0.66	6	6.58

Table 18: Boom Truck # 33899 DPM Emission Summary

The boom truck is equipped with an indirect injection, naturally aspirated Deutz 912W series engine. Lab testing has shown that the 912W series generate more DPM than the 413W series, and this is reflected in the field data above.

8.0 SAMPLE FLEET DPM EMISSIONS

The following table summarizes the DPM emissions for all the vehicles tested at the Kidd Creek Mine. Total DPM mass emissions represent the total mass of DPM in grams emitted by the vehicle into the mine environment during the testing period. The next column is the average DPM emission rate (in grams per hour) for each vehicle, weighted against the time spent at each distinct operating mode.

Vehicle	Total Mass (g)	DPM Rate (g/hr)
LHD 33635 8-yd	45.8	22.0
LHD 33616 6-yd	43.2	15.6
LHD 33626 3.5-yd	37.8	23.6
LHD 33638 8-yd	43.1	22.1
Truck 33661	50.4	19.9
Truck 33661 repeat	43.5	12.0
Chevrolet truck 33348	4.0	3.3
Ford truck 33325	2.6	1.6
Dodge truck 33336	4.3	3.1
Kubota Tractor 33966	24.5	22.7
Kubota Tractor 33952	16.2	13.3
Driftec Shotcreter 33973	12.4	6.3
Getman Scissorlift 33872	10.8	6.0
Getman Boom Truck 33899	19.5	12.9

Table 19: Sample Fleet DPM Emissions

8.1 General Discussion

Several key points are identified on Table 19. Generally, the HD LHD production vehicles have the highest DPM mass emission rates, followed by the production haul trucks, tractors, utility vehicles, with pick up trucks having the lowest.

The older technology two-stroke engine on the Wagner ST3.5 is the likely reason that it has the highest emission rate of the LHD's. The modern four-stroke Series 60 and 50 engines are cleaner. The Series 50 engine in the 6 yard LHD is known to have lower DPM emissions than the Series 60 engine in the 8 yards. This is reflected in the field data. The two 8 yard LHD's have similar average DPM emission rates for similar duty cycles, which supports the repeatability of the test method.

Truck 33661 (repeat) spent almost 40% of the test time idling. This is reflected in the lower DPM emission rate from Truck 33661. Interestingly, during those 84 minutes of idling, 3.25 grams of DPM (or 7.5% of the total) were released into the mine environment. Simply shutting the engine down could have stopped this pollution. Although 3.25 grams may seem small, it is more than the total amount released by the Ford pickup during the entire trial period.

The Kubota tractors demonstrate the wide emissions variability seen with in-use mechanically controlled engines. Fuel system problems are suspected with tractor 33966 and it should be pulled from service for repair. The DPM emission rate from tractor 33966 exceeds all of the HD production vehicles except the two-stroke Wagner ST3.5. This is important because at approximately 50% power utilization, the mine is only getting 27 HP of work from the Kubota tractor but is absorbing the same DPM burden as an 8-yard LHD.

The utility vehicles have reasonable DPM emission rates compared to the HD production vehicles. They are usually purpose built for mining and as such the engine and transmission ratios are selected for optimum engine operation. The DPM emission rates of the Deutz 913W engine in the boom truck and the Deutz 413W engine in the scissorlift highlight the difference between these series of engines. Laboratory testing has shown that the 413W series has a lower DPM emission rate and this is reflected in the field data.

The Ford pickup had the lowest DPM emission rate of all the vehicles tested. This is likely due to the deration of the engine from factory specifications. The Dodge pickup was next, due to the use of a base industrial diesel design with a modern electronically controlled radial fuel injection pump. While in last place among the pickups, the Chevrolet truck emissions were still significantly better than the next worst vehicle, the Getman scissorlift. The Chevrolet truck L65 is based on a design from 1982 and is obsolete. The new Chevrolet engine the Duramax 6600 is being tested by the mine, but was not included in this study because of scheduling conflicts.

8.2 Ambient Operator Exposures:

During the field study, ambient air samplers were mounted in each vehicle cab and worn by the vehicle operator. The following table highlights results of measurements of personal exposure of operators to DPM. The analysis was done using the NIOSH 5040 method.

Operator's Vehicle	EC (mg/m ³)	OC (mg/m ³)	TC (mg/m ³)	EC/OC
LHD 33635 8-yd	0.094	0.098	0.191	0.96
LHD 33616 6-yd	0.137	0.282	0.419	0.49
LHD 33626 3.5-yd	0.229	0.173	0.401	1.32
LHD 33638 8-yd	0.088	0.122	0.210	0.72
Truck 33661	0.184	0.161	0.345	1.14
Truck 33661 repeat	0.180	0.159	0.339	1.13
Chevrolet truck 33348	0.206	0.170	0.376	1.21
Ford truck 33325	0.089	0.061	0.150	1.47
Dodge truck 33336	0.129	0.064	0.193	2.01
Kubota Tractor 33966	0.287	0.262	0.549	1.09
Kubota Tractor 33952	0.247	0.144	0.391	1.72
Driftec Shotcreter 33973	0.087	0.053	0.140	1.63
Getman Scissorlift 33872	0.100	0.057	0.157	1.75
Getman Boom Truck 33899	0.112	0.074	0.186	1.52

Table 20: Operator Exposures

Due to the importance of obtaining real duty cycles, no attempt was made to isolate the test vehicles from other sources of DPM. In particular, DPM exposures of operators during cycles with large portions of ramp travel time should be very carefully considered.

In general, the ambient exposures are a good indicator of tailpipe emissions. The table correctly predicts the Kubota tractor operator is being exposed to high DPM concentrations and the Ford truck operator is exposed to lower levels.

8.3 Tailpipe Elemental Carbon / Organic Carbon

The following chart shows the tailpipe EC/OC split for each of the vehicles in the test fleet. EC/OC split can provide information about the composition of DPM emitted by the engine. Electronically controlled engines operating at high load usually have a higher EC/OC split. Mechanical engines at low loads generally have lower EC/OC.

Vehicle	Tailpipe EC/OC
LHD 33635 8-yd	4.47
LHD 33616 6-yd	6.04
LHD 33626 3.5-yd	0.74
LHD 33638 8-yd	3.09
Truck 33661	1.74
Truck 33661 repeat	2.56
Chevrolet truck 33348	2.63
Ford truck 33325	1.40
Dodge truck 33336	N/A
Kubota Tractor 33966	0.35
Kubota Tractor 33952	N/A
Driftec Shotcreter 33973	1.26
Getman Scissorlift 33872	0.50
Getman Boom Truck 33899	1.68

Table 21: Tailpipe EC/OC Split for Sample Fleet

HD LHD's have the highest EC/OC split, which is a well-known characteristic of modern electronically controlled diesel engines. Mechanical engines have a more even split, in some cases dropping below unity. LHD 33626 has an EC/OC split also lower than one, which is in accordance with observations previously made on the characteristic of two-stroke engines.

8.4 Sample Fleet DPM Burden

The following chart shows the division of total DPM burden among the sample test fleet. The breakdown is based on the weighted average DPM emission rate for each vehicle during the sampling period only.

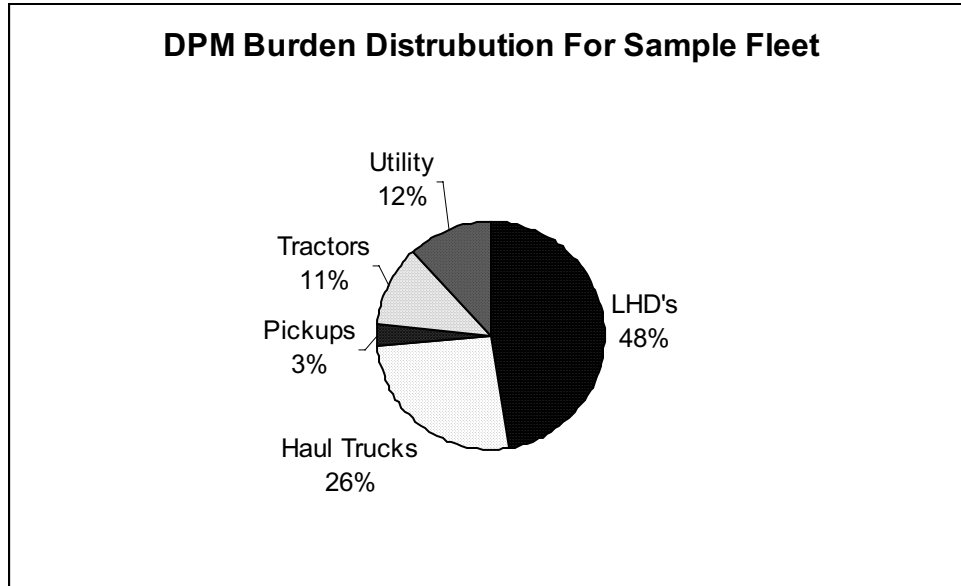


Figure 15: DPM Burden Distribution For 14 Vehicle Sample Fleet

HD vehicles including LHD's and haulage trucks were responsible for 74% of the total DPM burden emitted by the sample fleet. LD vehicles were responsible for 26%.

In order to adequately determine the relative contributions of LD and HD vehicles to the underground DPM burden, the sample fleet data must be extrapolated to the entire Kidd Creek fleet.

9.0 KIDD CREEK FLEET DPM EMISSIONS

To estimate the underground DPM burden at Kidd Creek mine, the sample fleet test data was extrapolated to represent the entire Kidd mine diesel fleet. Since not every type of vehicle underground could be tested so the following assumptions were made to simplify the comparison.

- 1) Total U/G fleet of 156 vehicles (from Kidd records, see Table 1).
- 2) The total fleet is composed only of vehicles from the 14-unit sample fleet.
- 3) The total fleet operates over the same duty cycles as the sample fleet.
- 4) The total fleet operates the number of hours outlined in Table 21 below (hourly data provided by Kidd Maintenance).

Thus, our model fleet is composed of 20 LHDs, ten 8-yard, three 6-yard, and seven 3.5-yard. Both haulage trucks are 30t EJC430s. The 42 vehicle pickup truck fleet is 79% Chevrolet, 19% Dodge and 2% Ford. All 18 tractors are Kubotas (average of the two tested). The utility vehicle fleet is composed of 25 shotcreters, 25 boom trucks and 24 scissor lifts, for a total of 156 vehicles.

The last assumption about the utility vehicle breakdown is probably the least valid. The wide diversity of utility vehicles underground made selection difficult, each vehicle is almost unique. Finally vehicles powered by Deutz 413W and 912W series engines were selected in addition to a vehicle with a newer electronic engine as these types of engines are slowly starting to replace the Deutz at new equipment purchase or repower.

Vehicle Type	Number	DPM rate (g/hr)	Utilization (hr/yr)	DPM Burden (kg/yr)
8 yd LHD	10	22.05	2583	569.55
6 yd LHD	3	15.62	1880	88.07
3.5 yd LHD	7	23.63	1583	261.85
30t Trucks	2	15.95	1600	51.04
Chevrolet pickups	33	3.32	698	76.53
Ford pickups	1	1.56	698	1.09
Dodge pickups	8	3.07	698	17.13
Tractors	18	18.00	942	305.21
Shotcreters	25	6.35	651	103.33
Scissorlifts	24	6.03	686	99.34
Boom trucks	25	12.88	779	250.82

Table 22: Model Fleet Composition And DPM Burden

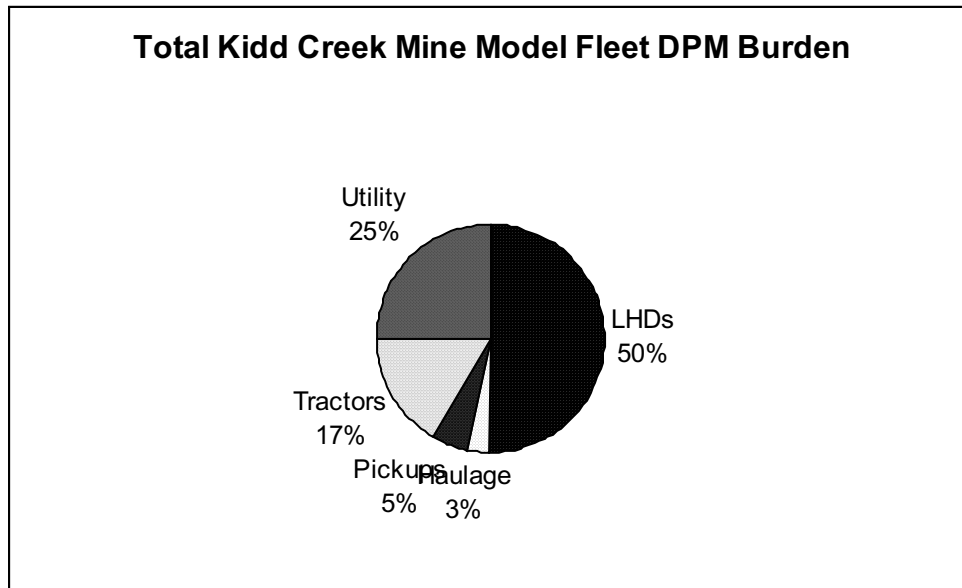


Figure 16: Total Kidd Creek Mine Model Fleet DPM Emission Burden

For the model fleet, HD vehicles (LHDs, haulage trucks) are believed to be responsible for approximately 53% of the total underground DPM burden. LD vehicle (tractors, pickups utility) are responsible for about 47% of the burden.

10.0 CONCLUSIONS

10.1 General Conclusions

The Kidd Mine model fleet is composed of 14% HD and 86% LD vehicles. Despite that fact, the underground DPM burden is fairly evenly split between the HD and LD vehicles. HD vehicles and LHD's in particular remain the major contributors to DPM underground. However, LD vehicles are still producing 47% of the underground DPM burden and must be a part of any DPM control strategy.

The DPM mass emission data contained in this report could form the basis for a more comprehensive model of the Kidd Creek diesel fleet. A more refined model could allow strategic planning for DPM emissions and prevent local areas of high concentration by monitoring vehicle distribution in the mine. Emissions data should be used to develop a DPM reduction program including implementation of control technologies.

10.2 Engine Operating Modes

Steady state engine operation promotes low DPM emission rates. Emission control systems on HD vehicles such as turbo charging and charge air-cooling perform best over steady state duty cycles. Traffic management and roadway maintenance can help vehicles to achieve this on ramp sections. Somewhat surprisingly, ramp descent in particular can be a high emissions transient cycle, depending on local ramp conditions.

Unnecessary engine idling can be a significant source of DPM emissions. Vehicle engines should be shut off wherever possible.

10.3 Engine Type, Technology and Maintenance

Even when electronically controlled, older technology two-stroke engines are not able to achieve the same DPM emissions performance as four-stroke engines.

Different engine models from the same manufacturer can have different DPM emission rates. Detroit Diesel Series 50 engines were found to be cleaner than Series 60, while Deutz 413W series were cleaner than 912W. Laboratory engine testing supports these field results.

Engine maintenance has a large effect on DPM emissions. Of two identical tractors, the unit with an obvious fuel system defect had a 41% higher DPM emission rate than the unit in good condition. The operator of this particular vehicle was exposed to the highest ambient DPM concentrations seen during the test.

Engine de-rating, as demonstrated on the Ford pickup, can have a beneficial effect on DPM mass emissions.

11.0 RECOMMENDATIONS

The Kidd Mine should implement a DPM mitigation strategy, which includes the following components:

- 11.1) Start by applying DPM control technologies to as many 8-yard LHD's as possible. These vehicles are responsible for the largest single portion of the mine DPM burden. Retrofitting all the Toro 501D 8-yard LHD's would allow the maintenance department to maintain one common system and stock of spare parts for one type of vehicle.
- 11.2) Next, DPM control devices should be retrofitted to the Kubota tractor fleet, as they represent the second largest contributor to concentrations of DPM from a single type of vehicle.
- 11.3) After successful implementation of the above two system, DPM controls should be considered for the utility vehicle fleet, starting with the Deutz 912W series engines. Integration of DPM controls for the utility fleet will be a challenge due to its diversity, but still important as they are a major contributor.
- 11.4) Pickup trucks and haulage trucks are lesser contributors and can scheduled for retrofit at a later date.

This report will not provide any recommendations for DPM emission control devices. The reader is referred to the Diesel Emissions Evaluation Program's (DEEP) two major studies on these devices at www.deep.org.

The Kidd Mine fleet DPM model should be further refined to more closely match the vehicles actually used underground. In addition, the DPM model could be combined with a mine ventilation model to provide the ventilation department with predictions of local ambient DPM concentrations throughout the mine.

The pick up truck fleet has the highest turnaround of vehicles in the mine. Further emissions testing should be performed on the pickup truck fleet including non-derated Ford trucks and newer GM Duramax 6600 engines to provide information for a vehicle purchasing strategy.

The Kubota tractor 33966 should be pulled from service and have the fuel system defect corrected, as it is exposing the operator to high DPM concentrations.

ACKNOWLEDGEMENTS

The authors would like to thank the following individuals for their assistance:

Falconbridge – Kidd Mining Division: Alain Landry, Fern Monette, Dennis Sasseville
NRCAN – CANMET: Michel Grenier, Vince Feres, David Young, Francois Tang