A. Habibijavanbakht, R.B. Kramer and A.D.S. Gillies, Investigating diesel particulate matter reduction using local ventilation changes in a U.S. industrial commodity mine – case study, Society of Mining Engineers Annual Meeting, Pre print, Feb 2016 16-102, accepted.

Investigating Diesel Particulate Matter Reduction Using Local Ventilation Changes In A U.S. Industrial Commodity Mine – Case Study

Arash Habibi, and Richard Kramer, Tronox Corporation, Green River, WY, U.S.A.
Stewart Gillies, Missouri University of Science and Technology, Rolla, Mo, U.S.A.

Abstract

Diesel Particulate Matter (DPM) measurements were taken at Tronox's Westvaco Trona mine in Wyoming. Both shift-average and real-time monitoring using Elf pumps and Airtec analyzers, were used. The mine's underground transportation fleet consists of more than 250 diesel-powered vehicles. A vehicle monitoring log tracked fleet usage during the test; logged data consisted of vehicle type, direction of travel, and time. The log was used in analysis to determine the DPM spread rate, of normally operating equipment, in the different entries with respect to vehicle location. Airflow velocity measurements at the stations were taken during the survey. The survey results also identified vehicles with higher emission rates. An ECOM gas and a MAHA DPM analyzer, both located in the mine's underground emission shop, were used to obtain various vehicle emission rates. The correlation of the workshop and field measurements was investigated with regard to the machine activity, fuel usage and atmospheric conditions. The results were used to identify and execute a ventilation project to reroute 45% of diesel shop air back to intake entries, by interlocking an automated door and a regulator. The result is reduced DPM downstream.

Introduction

DPM has been classified as a potential occupational carcinogen by the National Institute for Occupational Safety and Health (NIOSH).The Mine Safety and Health Administration (MSHA) rule governing DPM exposures in metal and nonmetal mines cites total carbon (TC), a summation of elemental carbon (EC) and organic carbon (OC) obtained by NIOSH Method 5040, as a surrogate for determining DPM exposures (Noll, 2006). MSHA personnel use the 1973 sampling criteria outlined by the American Conference of Government Industrial Hygienists (ACGIH) for collecting compliance-based respirable and inhalation samples in metal/nonmetal mines. Instrumentation developments are allowing improved real time monitoring of ventilation parameters. DPM is within the aerodynamic particle size range of the samplers used for respirable and inhalable dust measurements. If a sampler used by MSHA to collect inhalable or respirable dust samples in underground metal/nonmetal mines was used to collect DPM, both the DPM and mine ore dust would accumulate on the sample filter (Noll, 2006).

To comply with the requirement and lower the DPM exposure, mines are implementing a variety of control technologies such as emission based maintenance programs where adjustments or repairs are performed on the vehicles (McGinn, 2000).

Measuring Methods

NIOSH 5040

The NIOSH 5040 method is an established technique for measuring both organic and elemental carbon. The process involves drawing sampling air through a DPM cassette at a flow rate of 1.7 liters per minute to collect soot onto quartz filters inside the cassette. After sampling, punches of these filters are placed inside a 5040 oven for analysis. The oven first measures organic carbon (OC) by progressively increasing its temperature up to 870 °C in four steps in a pure helium environment. The lack of oxygen prevents EC from reacting. OC is oxidized to carbon dioxide and is reduced to methane. The methane is measured using a flame ionization detector (FID). EC is then measured by reducing the oven temperature and then raising it back up to 900 °C in a helium/oxygen atmosphere (Janisko, 2008). EC reacts with oxygen to form carbon dioxide. Once again, the carbon dioxide is reduced to methane and the methane is measured with an FID.

Because a suitable reference material is not available for determining the organic and elemental carbon content of a complex carbonaceous aerosol, only the accuracy of the method in the determination of total carbon (TC) could be examined (NIOSH Manual). During the survey, 13 Elf pumps were at the stations. The cassettes were then sent to the laboratory and the results were adjusted to calculate the concentration for the period of 8 hours (Habibi et al, 2014).

Real Time Monitoring

Several monitoring devices were used to measure DPM concentration. The FLIR Airtec only became commercially available in 2011 subsequent to NIOSH development (Noll et al., 2007). It measures the Elemental Carbon (EC) component of DPM by a laser scattering approach. Results from the Airtec can be compared directly with SKC system DPM evaluations. Both new instruments have been evaluated underground for robustness and reliability; tests were done in coal and metal/non-metal mines. Two Airtec units were used in this study, upstream and downstream, the Airtec results were compared against the NIOSH method.

Preliminary Survey

A comprehensive study was conducted to evaluate the DPM concentration is various locations. The DPM test was conducted in two stages. The primary survey covered the south mine area where a majority of diesel equipment commutes on a regular basis. The secondary survey was done during the LW move where the diesel-tractored support haulers were moving the LW shields from recovery room to the set up face. Moving the LW shields is considered the most concentrated diesel activity in the mine's opearation. Four divided sections were chosen in a way to cover the main mine developments. Each station consisted of the main travel roads, back road, and belt drifts. At each station, a real time Airtec was placed at the main travel drift. The Elf pumps were placed in the main roadway, as well as the other drifts, to measure the TWA concentration of DPM (Habibi et al 2014). Figure 1 shows the stations layout throughout the mine.

The intake air from 8 Shaft dilutes the air after the shop split. The DPM concentration increases inby the first station. The vehicles emit DPM, this emission rate increaseswhen machines are under load. The results show that DPM concentration at shop area is significantly lower than the reading in the Main Developments. The Airtec and NIOSH 5040 cassettes results are in the acceptable range. The leapfrogging survey was conducted in between all the stations. It was observed that LHDs are the main DPM source; with concentrations as high as 150μg/m^3 TC measured.

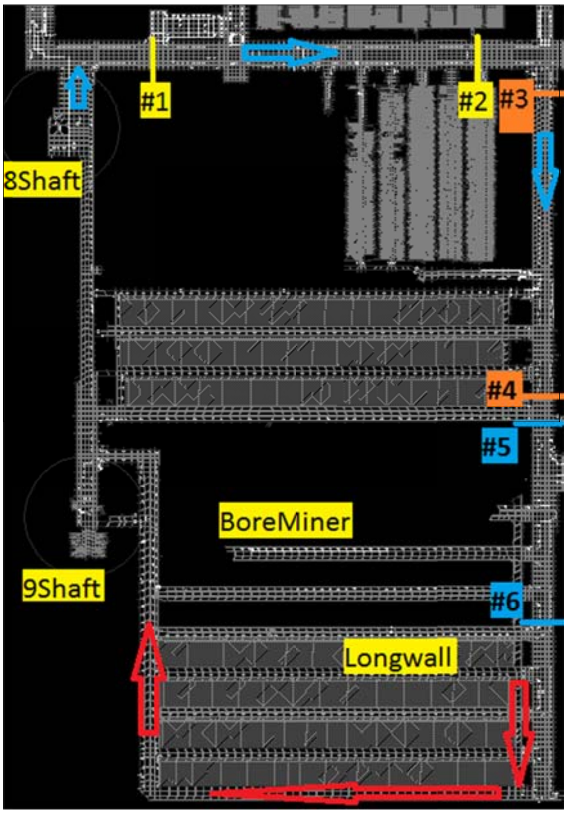

Figure 1. Station layout throughout the mine.

Further DPM sampling was conducted across the entire mine. The purpose of this sampling was to understand the DPM spread and dilution rate throughout the mine. Thirteen Elf pumps were distributed in all of the Main Developments, bore miner panels, LW headgate and tailgate, diesel shop (at the regulator), and 9 Shaft. The concentration was adjusted according to running time period on each pump.

Two Airtec monitors were placed at the same station for a period of about three hours. The results show readings differed by approximately 3%. One of the Airtec monitors was then moved down to station #6. Figure 2 shows the DPM concentration for the entire mine as measured by Elf pumps (NIOSH 5040).

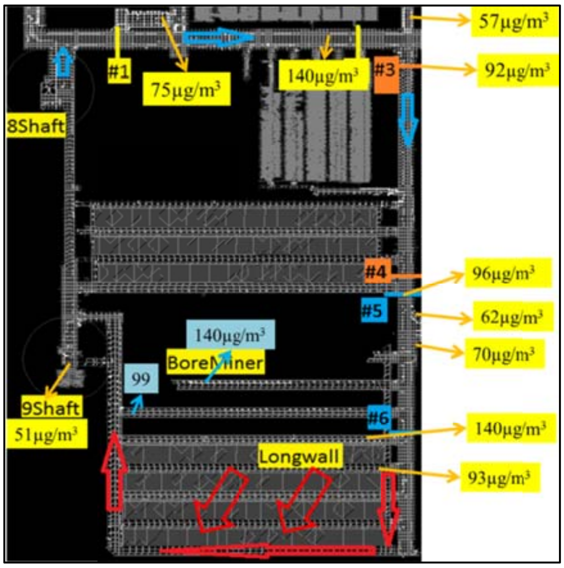

Figure 2. TC concentration via Airtec at station #2

The concentration at station #2 is relatively high (140 µg/m^3). Approximately 60 m^3/s of intake air (carrying DPM at 57µg/m3) from 5 Shaft enters the intersection and mixed with the air from Station #2. This mixing reduced the concentration to 92µg/m^3. The survey results show the DPM concentration slightly increases between station #3 and #4. An additional fresh air split enters at station #4 (592 S, station #5) which further reduced the DPM concentration to 62µg/m^3. The air then enters the production faces. The DPM concentration increased to 140 µg/m^3 at 9HG development as the result of higher than usual traffic (Habibi et al, 2014).

Proposed Project

The monitoring results showed relatively high concentration of TC in Main Developments (Station #2). Approximately the 50 m^3/s (100 kcfm) enters into the 8 shaft shop and warehouse area and dumps into the mine's return air system. From the measured data, Mine Engineering proposed a project to reroute the main diesel shop air back to the main entries. The regulatory guidelines was reviewed. According to the Title 30 CFR, Part 57.4761 for Underground Shops:

"To confine or prevent the spread of toxic gases from a fire originating in an underground shop where maintenance work is routinely done on mobile equipment, one of the following measures shall be taken:

use of control doors or bulkheads, routing of the mine shop air directly to an exhaust system, reversal of mechanical ventilation, or use of an automatic fire suppression system in conjunction with an alternate escape route. The alternative used shall at all times provide at least the same degree of safety as control doors or bulkheads.

(a) Control doors or bulkheads. If used as an alternative, control doors or bulkheads shall meet the following requirements…

(b) Routing air to exhaust system. If used as an alternative, routing the mine shop exhaust air directly to an exhaust system shall be done so that no person would be exposed to toxic gases in the event of a shop fire.

(c) Mechanical ventilation reversal. If used as an alternative, reversal of mechanical ventilation shall…

(d) Automatic fire suppression system and escape route. If used as an alternative, the automatic fire suppression system and alternate escape route shall meet the following requirements…

The main underground shop at the Westvaco Mine is ventilated with air from one of the main mine fans. The layout of the shop is such that air crosses through the mine's main warehouse, then the shop areas and the tool room. The air then is exhausted via 6 Shaft as shown in Figure 3. The layout works well to ventilate the shop area, warehouse and tool room; however it does take a significant quantity of air.

A separate ventilation infrastructure is also used in the main shop and is set up to ventilate contaminated air from welding stations, emission shop, and a battery charging station. The air from these areas reports to 6 Shaft. Staff in the Mine Engineering Department designed an alternative that maintained Shop ventilation as well as provide more air to the operating panels.

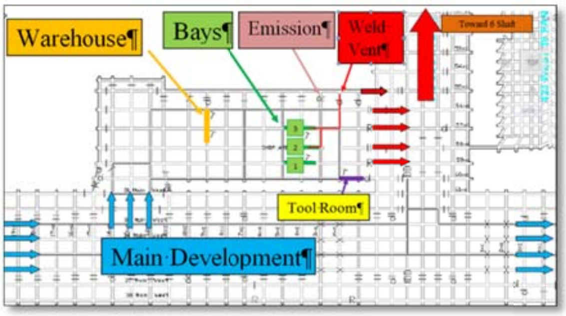

Figure 3. Present Shop Ventilation System

In order to increase the air quantity in working faces, a portion of main shop air was rerouted back to the main development (Figure 4). Currently, the shop is ventilated with approximately 50m^3/s (100 kcfm). As shown in the figure, a hydraulic door and actuated regulator will be installed at the east end of the shop. The door and the regulator will be interlocked and can be controlled by switches, one located near the shop and one on the surface, accessible by the hoistman. In case of any unexpected event that impacts the shop atmosphere, the system will close the door and open the regulator, which prevents shop air from reaching the production areas.

Executing the project is a far more efficient use of fresh air,currently exhausting out, by bringing it back to ventilate the working faces and provide a better environment for the working face. There are no significant activities being undertaken in the warehouse or that contaminate the air. The proposed changes do not alter the ventilation systems for battery station, emission shop and the welding stations.

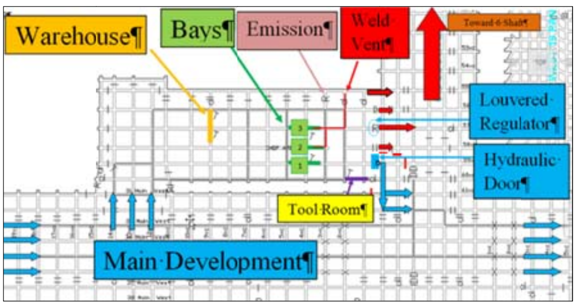

Figure 4. Proposed Ventilation System

Installation and Commissioning

Upon approval the project by management, the project was submitted to MSHA as an addendum to ventilation plan. The plan was also shared with the tate Mine Inspectors Office.

The execution took place in multiple steps. The project required labor-intensive clean-up. Both hydraulic door and regulator locations were constructed in old warehouse storage areas. Multiple blasts were conducted to remove old wooden stoppings that were no longer needed for service. Temporary stoppings were built prior to the blasts to divert the air to the Main Development (as shown in Figure 4). Excessive floor heave (specifically at middle of the mine entries) was a challenge to be considered. As the entries were over thirty years old, the floor heave was approximately 0.5m (1.5ft). Figure 5 shows an asphalt milling machine (Asphalt Zipper) being used to trim floor in the installation area.

The Kennedy door and regulator were installed in the locations. The door and regulator were wired back to a nearby PLC controller The controller consisted of a touch screen display, back up battery (UPS), to power the system in case of emergency, as well as, fans to vent to the returns any Hydrogen produced during the charging process.

Figure 5. Asphalt Zipper Cutting the Installation Sites

The door consisted of two chain–driven, electric motors. The doors were programed to operate separately. The doors cycle in approximately 30 seconds—very fast for this application, but slow enough to not be a hazard to personnel in the area. The system used indicator lights on the nearby junction boxes to show the status of door and regulator (so an employee could determine the status of the door and regulator from a distance). The 8Shaft hoistman, located on the surface, can monitor the door status and is capable of closing the door and opening the regulator if needed. Figure 6 and 7 show the door and controller.

Figure 6. Kennedy Door Installation

The louvered regulator was designed and built to overcome the 2 Pa (8 In.WG). The regulator, once it is fully open, could have an orifice of 6.5m^2 (70 ft^2). The opening is big enough to accommodate 140m^3/s (300 kcfm) if necessary. Figure 8 shows the louvered actuated regulator and the Kennedy man door which was installed by the regulator.

Figure 7. PLC Controller

A junction box was also placed at the regulator location it indicates the status and percentage of regulator opening.

Figure 8. Louvered Regulator Installation

The emergency plan was written and programmed to the PLC. In case of emergency (such as a fire at diesel shop or a power loss at 8 Shaft), the door and regulator can be activated by either the 8 Shaft hoistman, diesel shop switch, or emergency button located at the door. Upon activation, the system goes through multiple steps to divert 100 percent of shop air directly to return airways. First, the buzzer goes off for 10 seconds to inform any employee in the area. Then, the door begins to close(this door closing takes approximately 30 seconds). After the door is closed, the buzzer goes off for another 10 seconds. Finally, the regulator is opened to 40 percent. The opening will ventilate approximately 50m^3/s (100 kcfm) in the shop area to the returns. The emergency system is tested once a quarter and documented in weekly ventilation report. The system is currently in service.

Monitoring Results and Discussion

The secondary air DPM survey was conducted once the air door and regulator were installed. The air quantity measurements were taken at Station #1 and #2. The Elf pumps were installed in Main Developments (Station #1 and #2), Shop door and Shop regulator. An Airtec unit and a PDM 3700 dust monitor were also placed at Shop door location to determine the quality of the shop air entering back to the mine air circuit. Approximately 45 percent of total air entering the diesel shop area is reintroduced back to the Main Development for use in the mine works.

The results from the preliminary survey are shown in Table 1 (Habibi et al, 2014). The letters represent different entries from left to right. It was observed that DPM concentrations exhausting to 6

Shaft were close to station #1. In addition, high concentrations of TC were measured at Station #2. Airflow measurements were taken throughout the entire diesel shop area (every crosscut). The measurements were compared to the pre-installation measurements. All the measurements were higher except one station by tool room; this change was owed to leakage through a drive-thru curtain.

Table 1. NIOSH 5040 via Elf and Airtec TWA results.

Station #	Organic µg/m^3	Elemental µg/m^3		Total µg/m^3	
	NIOSH 5040	NIOSH 5040	Airtec	NIOSH 5040	Airtec
#1 A	38	21		59.5	
#1 B	33	34		75	
#1 C	30	30	26	69	65
#1 D	25	11		41	
Shop	57	25		81	
#2 A	40	57		105	
#2 B	30.4	31.5		68.9	
#2 C	46.7	99.2	93	151.8	14
#2 D	44	83		148	
9Shaft	38	19		66	

The airflow measurements at station #1 were similar or higher to the readings prior to the change. The airflow quantity at the shop and regulator were continuously monitored using ultrasonic anemometers. It was observed that higher airflow quantities were entering the diesel shop area (approximately 5 to 10 m^3/s). It was also observed, at any given time, approximately 25 to 30 m^3/s (50 kcfm) flows through the door.

Table 2 shows the DPM Concentrations at station #1, #2, shop door and the regulator. Figure 9 shows the EC concentration at the shop door.

Table 2. NIOSH 5040 via Elf and Airtec TWA results

Station #	Organic µg/m^3	Elemental µg/m^3		Total µg/m^3
	NIOSH 5040	NIOSH 5040	Airtec	NIOSH 5040
#1 A	NA	NA		NA
#1 C	22	15		37
Door	39	32	27	71
Regulator	41	33		74
#2 A	NA	NA		NA
#2 C	63	45		110

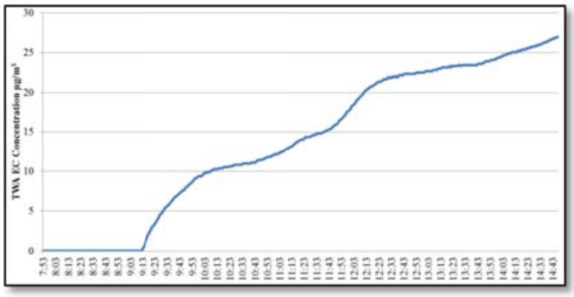

Figure 9. TWA EC Concentratio at Diesel Shop Door

The results show that a lower concentration of DPM was measured at Station #2. The reduction of 27 percent was observed. Cumulative dust concentration for the survey period measured by PDM 3700 was 0.15 mg/m^3.

The measurements were taken in a course of a working shift. However, it is important to note that DPM concentration in the mine atmosphere depend on the number of vehicles travelling to the shop and warehouse area, and it could vary in different shifts. The measurements were taken on day shift (similar to pre installation). The vehicle log showed that there were more heavy equipment activities on the pre-installation survey. The mine has upgraded over 25 light duty man trips and two heavy duty LHDs in the last two year. The cleaner, more efficient new engines have positively impacted the survey results.

Conclusion

This paper contains a plan to study, evaluate results and detailed planning, execution, and commissioning of a system to improve mine ventilation.

A comprehensive study was conducted on the DPM distribution and concentrations throughout the mine.

The following is a review of the results and observations:

- A periodic comprehensive DPM sampling could help the Mine to determine deficiencies of the ventilation network. High DPM concentrations were measured at the main development (station #2) as a result of high traffic and lower air quantity.
- The real time Airtec monitor readings and NIOSH 5040 readings were almost overlapped.

- 8 Shaft Diesel Shop: The results from all the surveys show that the DPM level at the Shop regulators was lower than 3ME readings. Therefore the Mine executed a ventilation project to reroute approximately 25 m^3/s air may reduce the DPM concentration at station #2 by 27 percent as the airflow increased by 9 m^3/s (18 kcfm). The project consisted of hydraulic door and regulator interlocked and controlled by a PLC controller.
- Post-installation DPM survey results could be impacted by the new light and heavy duty engines and DPF upgrades. The vehicle log shows more activities in the survey area on pre-installation day survey.

Acknowledgements

This paper was prepared with support from Tronox Westvaco Mine. This assistance is gratefully acknowledged as is the support efforts of other mine personnel.

References

ASTM Standard, 2002, BS ISO 16183, Heavy duty engines: Measurements of gaseous emissions from raw exhaust gas and of particulate emissions using partial flow dilution systems under transient test conditions. New York: American National Standards Institute.

Cantrell, B.K., and K.L.Rubow: Development of personal diesel aerosol sampler design and performance criteria. Min. Eng. 43:232–236 (1991).

Cantrell, B.K., and K.L.Rubow: Development of personal diesel aerosol sampler design and performance criteria. Min. Eng. 43:232–236 (1991).

Cantrell, B.K., and W. F. Watts, Jr.: Diesel exhaust aerosol: Review of occupational exposure. Appl. Occup. Environ. Hyg. 12:1019–1027 (1997).

Gillies, A.D.S. and Wu, H. W., Some approaches and Methods for Real-Time DPM Ambient Monitoring in Underground Mines, SME Annual Meeting, Feb 19-22 Seattle, Washington, 2012

Grau, R. H., III ; Robertson, S. B. ; Mucho, T. P. ; Garcia, F.and Smith, A. C., Practical techniques to improve the air quality in underground mines, NIOSH, Pittsburg Research Laboratory, Pittsburg, PA, USA, 2008.

Habibi. A, Kramer. R.B. and Gillies. A.D.S., A Comprehensive diesel particulate matter investigation in a U.S. industrial commodity mine, 10th International Mine Ventilation Congress, IMVC 2014, AUG 2014, Sun City, South Africa

Janisko, S. and Noll, J.D., 2008, Near Real Time Monitoring of Diesel Particulate matter in Underground Mines, 12th North American Mine Ventilation Symposium 2008, Wallace (ed), ISBN: 978-0-615-20009-5

McGinn, S., 2000, The relationship between Diesel Engine Maintenance and Exhaust Emissions, Final Report: DEEP, 2000, http://www.camiro.org/DEEP/Project_Reports/mtce_report.pdf

Mine Safety and Health Administration (MSHA), U.S. Department of Labor , "Final Rule 3 0 CF R Part 57," January, 2001.

MSHA, Mine Safety and Health Administration, 2009, 30 CFR part 7, Testing by applicant or third party, Code of Federal Regulations, Washington, DC: U.S. Government Printing Office, Office of Federal Register.

NIOSH Manual of Analytical Methods (NMAM), Elemental Carbon, Method 5040, Issue 3, 15 March 2003

Noll, J.D. and Janisko, S., 2007. Using Laser Absorption Techniques to Monitor Diesel Particulate Matter Exposure in Underground Stone Mines. In: Cullum B, Porterfield, D, ed. Proceedings for SPIE: Smart Biomedical and Physiological Sensor Technology V. Vol. 6759 Boston, Massachusetts: SPIE, pp. 67590P-1 67590P-11.

Noll, J.D., Timko, R.J., Schnakenberg, G.H., and Bugarski, A., 2006, "Sampling Results of Improved SKC Deisel Particulate Matter Cassette," Journal of Occupational and environmental Hygine, Volume 2, pp.29-37. ISSN: 1545-9624 print / 1545-9632 online

Operator's Manual, 5th Wheel Prime Mover, J.H Fletcher & Co, pp 151.

Title 30 Code of Federal Regulations. 30 CFR 75.302. 12/2010, USA