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디젤입자 채취를 위한 방법의 비교

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Occupational Exposure Monitoring for Diesel Particulate Matter Using Two Sampling Methods

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Abstract : This study was to compare the sampling efficiencies for monitoring of diesel particulate matter (DPM) using two different sampling methods; In-House PVC cyclone sampling heads and commercial airborne DPM (EC) sampling heads mounted on Dorr-Oliver cyclone heads. Personal exposure levels of DPM, analysed for elemental carbon (EC) were 0.004 - 0.2 mg/m^3 for the loader drivers and 0.005 - 0.34 mg/m^3 for the specialised mining vehicle (SMV) drivers were similar to previous study results. The highest result (0.34 mg/m^3) might be from an irregular production schedule and multiple job tasks requested. The results using the two sampling heads were not significantly different and it is thought that the In-House PVC cyclone with 37 mm quartz filter could be used in place of the commercial sampler as a preliminary screen in place of using the commercial sampler.

Key Words : diesel particulate Matter, elemental carbon, underground coal mine, sampling heads

1. Introduction

Diesel Particulate Matter (DPM) emitted from diesel-powered equipment consists of elemental carbon－EC, organic carbon-OC, diesel combustion aerosols, gases and vapours including sulfur compounds, nitrogen compounds, volatile organic compounds, aldehydes, carbon monoxide and carbon dioxide. Some of these emissions rapidly agglomerate together to form DPM aerosols (typically <1 µm), which are capable of penetrating into lower regions of the human lung and may cause short and long-term adverse health effects including respiratory and pulmonary disease, cardiovascular disease, nose and eye irritation, headache, fatigue and nausea[1-4]. According to a cohort study carried out by Vermeulen *et al.*,[5], it was reported that there is a possibility of increasing lung cancer mortality from exposure to diesel exhaust. However, no significant increased cancer risk was found in an Australian (New South Wales, NSW) Coal Industry cancer surveillance study[6]. As with surface mining industries, there are on-going efforts to reduce workers' exposure to DPMs in underground mining industries. Airborne DPM sampling is commonly carried out using a quartz filter mounted on a respirable cyclone sampling head as per the NSW's Mine Design Guideline (MDG-29) adopting NIOSH (National Institute for Occupational Health and Safety) Method 5040[7-9]. Most DPM have aerodynamic diameters less than I *µm*[10-18]. However, Noll and Birch (2004) considered the avoidance of coal dust from any potential interference of graphitic ore when collecting DPM[14]. In order to provide optimal separation between diesel and coal particles, the US Bureau of Mines (BOM) developed a size selective sampler

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with a cut point of 0.8 μm at 1.7 L/min and this sampler proved 90% effective in the exclusion of coal dust. Based on this, SKC tested their commercial airborne DPM sampling heads (37 mm quartz filter, part No 225-317) which meets NIOSH Method 5040 & MDG-29 conditions[14]. Their study results showed that the commercial sampling head eliminated most of the coal dust from the airborne sample collected in the coal mine and thus could collect low DPM concentrations in the presence of relatively high airborne concentrations of coal dust.

Even though DPM-EC exposure assessment is carried out in the mining industry, there is still a lack of exposure data reported. Because of the relatively expensive cost for the commercial sampler, it was considered trying the in-house sampler for initial investigation prior to following up using the commercial method. Thus, this study was to provide DPM-EC exposure data in a coal mining industry and provide comparative efficiency of the two different sampling methods; the in-house Casella PVC (polyvinyl chloride) cyclone sampling heads and commercially available airborne DPM sampling heads mounted on Dorr-Oliver cyclones using 37 mm quartz filters.

2. Methods

A total of 47 diesel vehicle drivers classified as Similar Exposure Groups (SEGs) (i.e. Loader Drivers and Specialized Mining Vehicle-SMV Drivers) working in an underground coal mine in New Zealand were involved. Airborne samples were obtained from the identified SEGs working two different work shifts, day shift (06:00−18:00 hrs) and night shift (18:00−06:00 hrs). The SEGs were working for 12 hours per day being equivalent to 15.2 days per months.

Personal exposure monitoring for respirable EC emitted from the two types of diesel vehicles was carried out mainly using Dorr-Oliver cyclone sampling heads composed of commercial airborne DPM sampling heads (SKC 37 mm quartz filter, Part No 225-317) as recommended by the NSW's Mine Design Guideline (MDG-29) adopting NIOSH Method 5040[7]. For comparison, respirable in-house PVC cyclone sampling heads (3M Casella cyclone, Part No 225-62) composed of heat-treated quartz filters (37 mm) were used for a limited number of samples. The two sampling heads are shown in Fig. 1.

Fig 1. Preloaded quartz filter cassettes for DPM exposure monitoring.

All filters were allowed to acclimatise in a desiccator with dried silica-gel for 24 hours prior to and after the sampling. They were then stored in clean petri dishes. Intrinsically safe air sampling pumps (Universal Pump SKC 224-PCMA4 and 224-PCMA8) were connected to sampling heads with the flow rate for respirable EC sampling set at 2.2 L/min for the in-house (Casella) PVC cyclone sampling heads and 1.7 L/min for the commercial airborne DPM sampling heads mounted on Dorr-Oliver cyclone samplers[7,15]. The pumps' flow rates were confirmed at the beginning and the end of the sampling period to ensure the required flow rates were within acceptable limits using a calibrated flow meter. The sampling heads were placed within the breathing zone of the SEG drivers. On completion of airborne sampling, all sampling filters were dispatched to an accredited analytical laboratory in NSW, Australia. The limit of detection for the sample analysis of EC was 0.1 μg/filter. A Microsoft Excel program was used for statistical analysis (Geometric Mean-GM and Standard Deviation-STDEV).

3. Exposure Standards

Currently there are no Australian national legal exposure limits for DPM (EC). However, the NSW Department of Primary Industries (MDG-29) recommends that an exposure limit of 0.1 mg/m^3 based on the work period of 170 hrs/month (8 hrs/day, 40 hours per week), while in this study the diesel vehicle drivers worked for 12 hours per day, (approx. 15.2 days per month being equivalent to 182.4 hours per month)[9]. In order to make up the working hour difference, there was a need to adjust Occupational Exposure Limit (OEL) as per MDG-29's *Exposure Reduction Factors for Extended Shifts*. The adjusted OEL for EC for 12 hours per day for a half month (approx. 15.2 days per month) is 0.093 mg/m^3 of EC.

4. Worksite Observation

Both Loader and Specialized Mining Vehicle (SMV) drivers involved in this study were exposed to DPM in the underground coal mine. The diesel vehicles (i.e. loaders and SMVs) had a DPM filtration system, such as a diesel particulate filter or a water filtration system. The loaders were used for transporting mine products or other tools/equipment. The SMVs were mainly used to transport miners in and out the underground coal mine. In-house exhaust emission testing (i.e. gases, particulates including DPM) for the diesel engines and filtration performance test for DPM filters was carried out once every one or two months. An air ventilation (exhaust) system had been installed to keep continuous negative pressure in the mine as well as to reduce excessive airborne contaminants and control environmental factors (i.e. humidity and heat emitted from diesel vehicle operation and coal excavation) by allowing outside fresh and dried air through the tunnel entry. In order to control and manage the underground air quality, carbon dioxide, carbon monoxide and explosive gas concentrations were continuously monitored. Furthermore, to minimise inhalational exposure to EC, personal respiratory protection (i.e. ESKO Safety Gear, PROMESH-P2 type with valve and active carbon filter; 3M, Disposable Air Purifying respirator with P2 type particulate filter) was provided to the diesel vehicle drivers working in the mine. However, all diesel vehicle drivers who were subjects in this study reported that they did not wear their respirators while they were driving the diesel vehicles because they were relying on the vehicle's air conditioning filtration unit and keeping all vehicle windows closed for control of exposure to contaminants. It was observed that the diesel vehicle drivers frequently opened their vehicle windows and got in/out of the vehicles to communicate with co-workers while underground. They were also occasionally involved in other tasks supporting other miners, vehicle drivers and co-workers, without wearing the respirators provided. During the exposure monitoring, in particular, it was found that the SMV drivers were involved in various job tasks compared to the loader drivers which involved in more frequent time out of their vehicles while they were underground.

5. Results

Table 1 represents the total data for personal EC exposure ranges for individual working groups at different working shifts prior to comparing the measurement data collected with the two sampling methods in Table 2 & 3. As seen in Table 1, loader drivers' EC exposure levels were GM-0.06 mg/m^3 (day shift) and GM-0.05 mg/m^3 (night shift). In the case of the SMV drivers, their EC exposure levels in day and night shifts were GM-0.09 mg/m^3 and GM-0.06 mg/m^3 respectively. The results for personal EC exposure monitoring using the two different sampling heads (i.e. in-house PVC cyclone sampling heads with quartz filters and commercial DPM sampling heads fitted to Dorr-Oliver cyclones) are outlined in Tables 2 and 3. The probabilities of the measurements were out of the 95% statistical significance thresholds, but the variations of the raw data collected and their GM values were similar one another even though their sampling cut points are different. From the raw data measured, 26% of the loader drivers (7 out of 27 samples) and 25% for the SMV drivers (5 out of 20 samples) exceeded the shift adjusted occupational exposure limit (0.093 mg/m^3).

6. Discussion

From the assessment results as seen in Table 1, the loader drivers' personal airborne DPM (EC) exposure levels

Table 1. Personal airborne elemental carbon (EC) exposure - all monitoring results

SEGs	Shift	Sampling time period	Number of samples	EC Range (min-max) (mg/m^3)
Loader drivers	Day	0700 - 1800 hrs	11	0.02 – 0.20
	Night	2200 - 0630 hrs	16	0.004 – 0.19
SMV drivers	Day	0700 - 1500 hrs	8	0.06 – 0.34
	Night	2200 - 0630 hrs	12	0.005 – 0.22

*SEG: Similar exposure group, GM: Geometric mean, STDEV: Standard deviation

Table 2. Personal airborne elemental carbon exposure monitoring results using commercial DPM sampling heads (Dorr-Oliver cyclone sampling heads) with 37 mm heat-treated quartz filters

SEGs	Shift	Sampling time period	Number of samples	Range (Min-Max) & Raw data (mg/m^3)	GM±STDEV (mg/m^3)	95% UCL (mg/m^3)
Loader drivers	Day	0700 - 1800 hrs	8	0.03 - 0.20 (0.03, 0.03, 0.04, 0.05, 0.07, 0.07, 0.15, 0.20)	0.05 ± 0.04	0.12
	Night	2200 - 0630 hrs	10	0.004 - 0.15 (0.004, 0.04, 0.05, 0.05, 0.07, 0.07, 0.08, 0.09, 0.13, 0.15)	0.06 ± 0.04	0.26
SMV drivers	Day	0700 - 1500 hrs	5	0.06 - 0.34 (0.06, 0.06, 0.08, 0.09, 0.34)	0.10 ± 0.13	0.49
	Night	2200 - 0630 hrs	12	0.005 - 0.22 (0.005, 0.03, 0.04, 0.05, 0.06, 0.07, 0.07, 0.09,0.09, 0.1, 0.12, 0.22)	0.06 ± 0.06	0.20

*SEG: Similar exposure group, GM: Geometric mean, STDEV: Standard deviation, 95% UCL: 95% upper critical limit (log-normal)

Table 3. Personal airborne elemental carbon exposure monitoring results using in-house PVC Cyclone Sampling heads with 37 mm heat-treated quartz filters

SEGs	Shift	Sampling time period	Number of samples	Range (Min-Max) & Raw data (mg/m^3)	GM±STDEV (mg/m^3)	95% UCL (mg/m^3)
Loader drivers	Day	0700 - 1800 hrs	3	0.02 - 0.07 (0.02, 0.04, 0.07)	0.04 ± 0.03	1.72
	Night	2200 - 0630 hrs	6	0.02 - 0.19 (0.02, 0.04, 0.1, 0.12, 0.12, 0.19)	0.08 ± 0.06	0.43
SMV drivers	Day	0700 - 1500 hrs	3	0.06 - 0.14 (0.06, 0.08, 0.14)	0.09 ± 0.04	0.55
	Night	2200 - 0630 hrs	NA	NA	NA	NA

*SEG: Similar exposure group, GM: Geometric mean, STDEV: Standard deviation, 95% UCL: 95% upper critical limit (log-normal)

were between 0.004 mg/m^3 – 0.19 mg/m^3, (Day shift: 0.02 mg/m^3 – 0.20 mg/m^3, Night shift: 0.004 mg/m^3 – 0.19 mg/m^3) which has 26% (7 out of 27 samples of the results in exceedance of the shift adjusted occupational exposure level (0.093 mg/m^3). It was noted that the exposure levels between the two shifts could vary depending on the daily work schedule for coal excavation and operation of the diesel vehicles. The SMV drivers' personal airborne DPM (EC) exposures were between 0.005 mg/m^3 – 0.34 mg/m^3 (Day shift: 0.06 mg/m^3 – 0.34 mg/m^3, Night shift: 0.05 mg/m^3 – 0.22 mg/m^3). The percentage of SMV drivers' EC exposure levels in exceedance of the shift adjusted exposure level (0.093 mg/m^3) was 25% (5 out of 20 samples). In particular, the SMV drivers were involved in various work tasks such as assisting other miners and co-workers, who may have been involved with vehicle maintenance, cleaning or moving construction materials, whilst the loader drivers stayed inside the vehicle cabins, thus their exposure levels were slightly higher than the loader drivers (Table 1). This study showed slightly lower EC results than the previous studies' results ranging 0.01 – 0.37 mg/m^3, 0.03 – 0.49 mg/m^3 and 0.01 – 0.42 mg/m^3 [11,12,16]. According to an epidemiologic study, the reported EC exposure range was 0.04 – 0.384 mg/m^3 [17]. The highest exposure level (0.34 mg/m^3) measured in our first-year assessment was also lower than the highest results in the following studies[11,12,16-18]. This highest result might be due to irregular production schedule and multiple job tasks involved. An air exhaust ventilation system was installed inside the underground coal mine to ensure continuous negative pressure in the underground coal mine allowing outside fresh air in through the mine tunnel entry. According to site observations and interviews with the drivers after their shifts, variable personal EC exposure levels could depend on workload amounts (pure production time conducted), multi tasks involved and supporting other miners as also suggested by Pratt *et al.*,[10]. In addition, individual work practices (*i.e.* frequent opening windows for communication, not wearing appropriate protective respirators) in the underground coal mine could cause variation of personal exposure to EC.

Two different DPM (EC) sampling heads (i.e.

commercial DPM sampling heads mounted on Dorr-Oliver samplers and in-house Casella PVC cyclone samplers-with 37 mm heat-treated quartz filters as suggested by the NIOSH Method 5040) were utilized for the diesel vehicle drivers (i.e. loaders and SMV drivers) involved in day and night shifts to compare their sample collection performance. From the comparison of the two DPM sampling heads' raw data in Table 2 & 3, it was thought that the measurement results using the in-house PVC cyclone sampling heads would be higher than that of using the commercial DPM sampling heads as the PVC cyclone sampling heads were designed to collect 4 μm cut point airborne particulates compared to the DPM's submicron size as well as the possibility of physical agglomeration (possibly $\geq$ 0.1 μm) between EC and other particulates from diesel emission and coal excavation. According to this study's results, however, all EC monitoring results taken by the two different DPM sampling heads were statistically similar as seen in Tables 1 and 2. Therefore, as per NIOSH Method 5040[7], it is thought that 37 mm quartz filters mounted on either of the two sampling heads could be useful as a preliminary airborne EC exposure assessment technique.

7. Conclusion

This study was carried out to assess occupational exposure to EC in underground coal mining and to provide further data to assist in the establishment of national or international occupational exposure limits for EC for those who are working with or around diesel vehicles in an underground coal mine. From the personal breathing zone EC exposure results, it appears that EC exposure levels in this study were similar with previous study results. Further data on personal airborne DPM exposures and follow up on subsequent health effects in the mining industries are needed. Interestingly, even though a limited number of samples were collected using the in-house PVC cyclone sampling heads with quartz filters, it appears that there were no significant differences between the raw data collected by the two different sampling methods even though their probabilities (95% UCL) were not statistically significant. It may thus be useful to use the in-house PVC cyclone sampler as a preliminary and conservative assessment technique (given its higher cut point) for EC exposure assessment.

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