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Effects of Diesel Exhaust Aftertreatment Devices on Concentrations and Size Distribution of Aerosols in Underground Mine Air

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Three types of uncatalyzed diesel particulate filter (DPF) systems, three types of high-temperature disposable filter elements (DFEs), and one diesel oxidation catalytic converter (DOC) were evaluated in underground mine conditions for their effects on the concentrations and size distributions of diesel aerosols. Those effects were compared with the effects of a standard muffler. The experimental work was conducted directly in an underground environment using a unique diesel laboratory developed in an underground experimental mine. The DPF systems reduced total mass of aerosols in the mine air approximately 10-fold for light-load and 20-fold or more for high-load test conditions. The DFEs offered similar reductions in aerosol mass concentrations. The efficiency of the new DFEs significantly increased with accumulation of operating time and buildup of diesel particulate matter in the porous structure of the filter elements. A single laundering process did not exhibit substantial effects on performance of the filter element. The effectiveness of DPFs and DFEs in removing aerosols by number was strongly influenced by engine operating mode. The concentrations of nucleation mode aerosols in the mine air were found to be substantially higher for both DPFs and DFEs when the engine was operated at high-load modes than at low-load modes. The effects of the DOC on mass and number concentrations of aerosols in mine air were relatively minor when compared to those of the DPF and DFE systems.

Introduction

In recent years, health issues associated with exposure to diesel particulate matter (DPM) and other, primarily combustion-generated, nano and ultrafine aerosols have received substantial attention from the public, government agencies, and in academia. Long-term exposure to combustion-related fine particulate pollution is perceived as an important risk factor for cardiopulmonary and lung cancer mortality (*1*).

Extensive utilization of diesel-powered equipment by the mining industry makes the reduction of underground miners' exposure to particulate matter and gaseous emissions from diesel-powered equipment a major challenge. Techniques for reducing worker exposure typically involve one or more of the following methods; improvements in mine ventilation, the curtailment of DPM and toxic gaseous emissions through improved engine maintenance, exhaust aftertreatment technologies, and the use of alternative fuels.

Diesel particulate filter (DPF) systems are recognized as an effective technology for removing DPM from the exhaust of diesel-powered equipment (*2–4*). Diesel exhaust filtration systems with disposable filter elements (DFEs) have been extensively used to control DPM emissions from permissible heavy-duty diesel-powered coal mining equipment since the early 1990s (*5*). Various models of DPFs and DFEs are currently accepted by the U.S. Mine Safety and Health Administration (MSHA) for controlling DPM emissions from underground coal mining equipment (*6–9*). Although a limited number of underground mining vehicles in operation are currently retrofitted with DPF and DFE systems it can be expected that this number will increase with advancements in engine, DPF and DFE technologies.

The findings of laboratory (*10*) and field studies (*3, 4, 11*) indicate that the introduction of various diesel exhaust aftertreatment technologies dramatically changes the physical and chemical properties of diesel aerosols and potentially changes their associated health effects. Growing evidence suggests that particle number, surface area, size, or perhaps some associated structural properties may affect nanoparticle toxicity, when compared with larger respirable particles of the same composition (*12*).

This paper summarizes the results of a study conducted to evaluate the effects that several types of DPFs, DFEs, and a DOC have on the concentration and size distribution of diesel aerosols in an underground mine. Previous studies on size-resolved characterization of diesel aerosols have typically been performed in well-controlled and ideal laboratory environments (*13–16*), on roads (*11, 16*), and in tunnels (*17, 18*). Since the size and concentration of diesel aerosol and semivolatile materials emitted by diesel engines have been shown to be strongly influenced by a number of complex processes (*19*), the National Institute for Occupational Safety and Health (NIOSH) chose to assess the aforementioned effects in an underground mine setting. In order to achieve this goal, while still preserving relative precision, a unique diesel laboratory was developed in a nonoperational limestone mine; the NIOSH Lake Lynn Experimental Mine (LLEM), near Fairchance, PA (*20*). Although the measurements were taken underground, the findings should also be applicable to other occupational settings where workers are performing their duties in proximity to diesel-powered equipment.

Experimental Section

A schematic of the laboratory layout is shown in Figure 1. The D-drift is approximately 530 m (1750 ft) long, 6 m (20 ft) wide, and 2 m (7 ft) high. The major components of the laboratory are an engine/dynamometer system, three sampling and measurement stations, and a ventilation measurement and control system.

The Isuzu C240, one of the most popular light-duty engines in U.S. underground coal mines, was operated at four steady-state engine operating modes (Table 1).

The modes were selected to cover a wide range of engine operating parameters such as exhaust temperatures and emission rates. The average exhaust temperatures at the inlet

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