Characterization of diesel aerosols emitted in work environment: NIOSH Engine Emissions Laboratory at Lake Lynn Laboratory

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Abstract

This study has been conducted with the objectives of identifying and characterizing nano and ultrafine aerosols emitted by diesel engines in work environment and evaluating the suitability of contemporary and emerging control technologies to reduce the exposure of workers to these particles, thereby reducing the associated occupational health risks. The project is part of larger National Institute for Occupational Safety and Health (NIOSH) efforts to investigate the role of nanoparticles in Chronic Obstructive Pulmonary Disease (COPD) and other occupational diseases. The physical and chemical properties and toxicity of the nano and ultrafine diesel aerosols will be characterized through a series of engine/dynamometer tests at the NIOSH Lake Lynn Laboratory experimental mine. Here NIOSH researchers developed a unique facility with an Engine Emissions Laboratory (EEL) integrated into an isolated drift entry. The knowledge obtained from this study will strengthen our understanding of the health implications related to the exposure to diesel particulate matter (DPM). In addition, the study should generate information on instrumentation and methodologies for monitoring exposure to diesel aerosols and the effects of various control technologies on the characteristics of diesel generated aerosols and gases in mine air. This research will enable the mining industry to make educated decisions on the proper control technology to reduce worker exposures.

Introduction

Diesel engines, widely used to power vehicles and equipment in mining, trucking, construction, and virtually any other industry, were found to be major source of nano and ultrafine aerosols in a number of occupational settings. Approximately 30,000 underground miners in the U.S. were found to be exposed to total carbon concentrations as high as 3,300 $\mu g/m^3$ [Cash and Baughman 2005]. In recent years, health effects associated with exposure to diesel particulate matter (DPM) and other primarily combustion-generated nano and ultrafine aerosols received substantial global attention from public, academia, and government. Pope et al [2002] established that long-term exposure to combustion-related fine particulate pollution is an important risk factor for cardiopulmonary and lung cancer mortality. Donaldson and Stone (2003) concluded that there is good toxicological evidence that ultrafine particles cause inflammation in the lungs even when composed of relatively low toxicity material. There is growing evidence suggesting that particle number, surface area or size, or perhaps some associated structural properties may affect nanoparticle toxicity in comparison with larger respirable particles of the same composition [Donaldson et al. 2003]. A great deal of attention has been paid to reduce miners' exposures to DPM, particularly after the U.S. Mine Safety and Health Administration introduced regulations limiting emissions from underground coal mining diesel powered vehicles [30 CFR 57.5001] and underground metal and nonmetal vehicles [30 CFR 57.5060]. The high demand for diesel emission control technologies for on-road and off-road vehicles sprouted development of exhaust aftertreatment technologies such as diesel particulate filters and reformulated fuels. Various laboratory studies [Mayer et al. 1995, Vaaraslahti et al. 2004] and a series of tests conducted in an isolated zone of an underground metal mine [Bugarski et al. 2006a, 2006b] have shown that physical and chemical properties of the aerosols emitted by diesel powered equipment are significantly changing with a number of engine parameters, particularly with the implementation of various emissions control technologies. The morphology and chemical composition of the nanometer and ultrafine diesel aerosols were found to be very size dependent [Maricq and Xu 2004]. In addition, since a significant fraction of aerosols emitted by diesel engines are volatile [Vaaraslahti et al. 2004], those properties, such as dilution ratio, temperature, humidity, and residence time [Kittelson et al. 2000, Khalek et al. 2000], are found to be dependent on physical and chemical processes taking place after the release of diesel aerosols into the environment. Therefore, for a better understanding of the effects of diesel aerosols on workers health it is essential to define critical physical and chemical properties and toxicity of the complex diesel aerosols present in an occupational environment rather than in a laboratory setting.

Objectives

This project is part of larger effort made by the National Institute for Occupational Safety and Health (NIOSH) to investigate the role of nano-particles in COPD and other occupational diseases. The specific objectives of the project are as follows:

•Characterize nano and ultrafine aerosols emitted by typical light- and heavy-duty diesel engines used by underground mining, construction, and trucking industries in the work place,

•Assess the effects of selected control technologies, such as the diesel particulate filter (DPF), diesel oxidation catalytic converter (DOC), and various fuel formulations on physical and chemical properties and in vitro genotoxic activities of diesel aerosols,

•Investigate the effects of aging and dispersion processes (i.e. time and distance from the emission source) on the properties of various nano and ultrafine aerosols emitted by diesel engines,

•Evaluate methodologies for monitoring worker exposure to diesel aerosols,

•Evaluate currently available and emerging instrumentation designed to monitor worker exposure to diesel aerosols.

Methodology

In an effort to bridge the gap between inherently inaccurate field and often unrealistic laboratory experiments, NIOSH developed a research facility that will allow extensive research into characterizing diesel aerosols in a simulated occupational setting. The NIOSH Engine Emissions Laboratory (EEL) has been established in the Lake Lynn Laboratory (LLL), an experimental mine located in Fairchance, PA. The layout of the laboratory is shown in Figure 1. The LLL offers an environment for field-evaluation of diesel technologies and their effects on air quality and workers' exposures to DPM and gases. This facility is designed to generate field results with precision and accuracy characteristic for results obtained in emissions laboratories. The diesel laboratory is located in the 530 m (1750 ft) long isolated drift entry referred to as "D-drift" (see Figure 2). This drift is approximately 6 m (20 ft) wide and 2 m (7 ft) high. Fresh ventilation air is supplied from the ventilation shaft located in "E-drift", situated immediately upwind and perpendicular to "D-drift". The 11.8 m^3/s (25,000 ft^3/min) Venturi meter and auxiliary fan is integrated at the downstream end of the D-drift. This system along with sliding air doors positioned at the upstream end of D-drift and the downstream end of the E-drift allow control and measurement of air quantities in the test zone (see Figure 2).

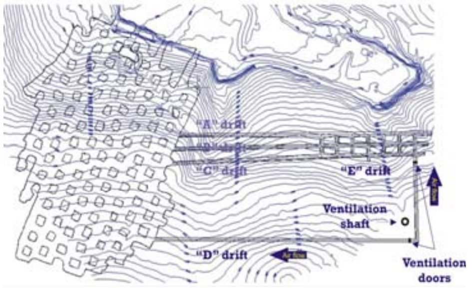

Figure 1. NIOSH Lake Lynn Laboratory Research Mine

The NIOSH EEL is planned around two dynamometer/engine systems that are designed to operate over both steady-state and transient conditions:

•150 kW eddy-current dynamometer currently coupled with an Isuzu C240 mechanically controlled, naturally aspirated diesel engine that is typically used in light duty coal underground mining applications such as personnel carriers (see Figure 3);

•400 kW eddy-current dynamometer currently coupled with a Mercedes Benz OM904 3MT32 electronically controlled, turbocharged engine that was recently introduced in underground mines as a replacement for outdated engines in medium- and heavy-duty applications.

Two ambient measurement and sampling stations are established: one upstream and one downstream of engine/dynamometer systems. The results obtained on those are used to quantify the net contributions of different test configurations to concentrations of aerosols and gases including carbon monoxide (CO), carbon dioxide (CO_2), nitric oxide (NO), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), and total hydrocarbons (HC) in the "D-drift" (see Figure 2). The tailpipe monitoring station shown in Figure 2 is dedicated to measuring concentrations of CO, CO2, NO, and NO2, in raw exhaust. State-of-the-art instrumentation, listed in Figure 2, is available to measure size distribution and collect samples for analysis of size-resolved chemical compositions of aerosols. NIOSH Analytical Method 5040, gas chromatography/mass spectrometry, high resolution analytical electron microscopy with x-ray diffraction, and inductively coupled plasma mass spectrometry are some of the methods that are used for chemical analysis. To evaluate the biological consequence of size-dependent changes in DPM chemical composition, surfactant-dispersed non-dissolved diesel aerosol samples will be analyzed by NIOSH Health Effects Laboratory Division (HELD) – Molecular Biophysics Team, using bacterial gene mutation assays and mammalian cell chromosomal and DNA damage assays [Wallace 1990; Shi at al. 2006].

Conclusion

This project, part of larger NIOSH efforts to investigate the role of nano-particles in COPD and other occupational diseases, should result in a better understanding of the physical and chemical properties and genotoxicity of diesel generated aerosols in an occupational setting. NIOSH-developed the EEL at LLL to allow extensive research on characterizing diesel aerosols in a simulated occupational setting. The knowledge obtained from this study will strengthen our understanding of health implications related to exposure to DPM. In addition, the study should generate information on instrumentation and methodologies for monitoring exposures to diesel aerosols and the effects of various control technologies on the characteristics of diesel generated aerosols and gases in mine air. This work will enable the mining industry to make educated decisions on proper control technologies to reduce worker exposures.

Literature

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Figure 3. 150 kW dynamometer/ Isuzu C240 engine system

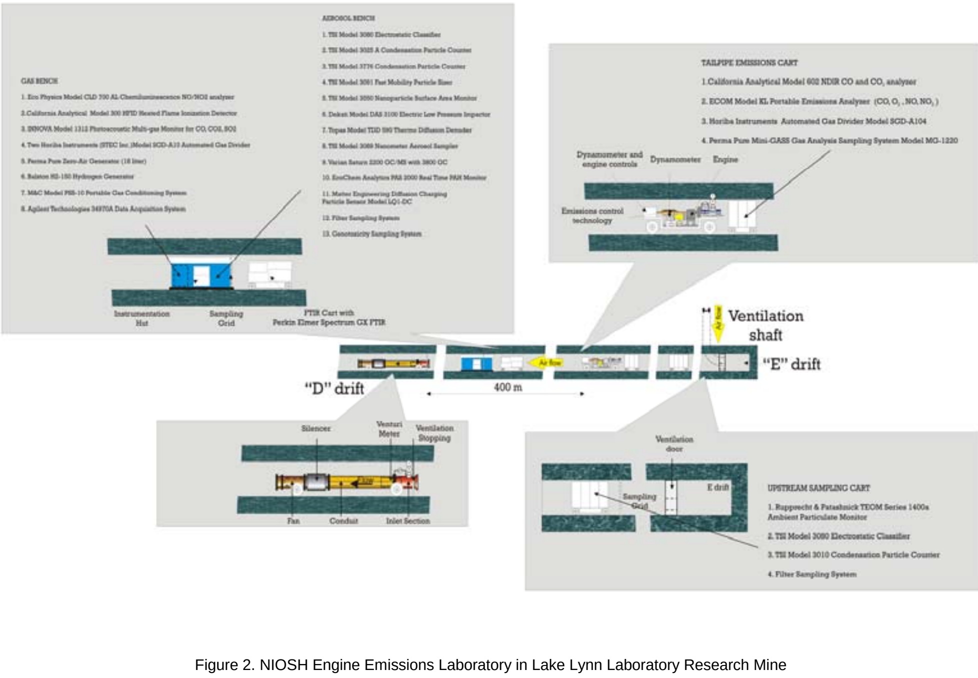

Figure 2. NIOSH Engine Emissions Laboratory in Lake Lynn Laboratory Research Mine