Integrated Approach to Reducing Exposure of Underground Miners to Diesel Particulate Matter and Gases

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Exposure of Underground Miners to Diesel Particulate Matter (DPM)

- In general underground miners are exposed to concentrations of diesel particulate matter (DPM) that are significantly higher then those of any other occupation.

  - MSHA compliance sampling (D.A. Cash, MDEC 2005) showed that underground miners in precious metal mines were exposed to TC concentrations as high as 3300 $\mu g/m^3$ and in crushed, broken limestone mines as high as 2980 $\mu g/m^3$.

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Rules Regulating Exposure of Underground Miners to DPM

- Underground metal and nonmetal mines
  - 30 CFR Part 57.5060 - Diesel Particulate Matter Exposure of Underground Metal and Nonmetal Miners;
  - Personal exposure limit, performance rule
- Underground coal mines
  - 30 CFR Part 72 - Diesel Particulate Matter Exposure of Underground Coal Miners.
  - Emissions standard, prescribed solution

Rules Regulating Exposure of Underground Miners to Gases Emitted by Diesel Engines

- Underground metal and nonmetal :

  30 CFR 57.5001. Safety and Health Standards Underground for Metal and Nonmetal Mines. Exposure Limits for Airborne Contaminants:

  - carbon dioxide (CO_2), ACGIH TLV-TWA is 5000 ppm;
  - carbon monoxide (CO), ACGIH TLV-TWA is 50 ppm;
  - nitric oxide (NO), ACGIH TLV-TWA is 25 ppm;
  - nitrogen dioxide (NO_2), ACGIH TLV-TWA is 3 ppm, ACGIH TLV-STEL (ceiling limit) is 5 ppm.

NOTE: MSHA adopted 1973 ACGIH standards.

Rules Regulating Exposure of Underground Miners to Gases Emitted by Diesel Engines

- Underground coal mines:

  30 CFR § 70.1900. Coal Mine Safety and Health. Exhaust Gas Monitoring.

  - carbon monoxide (CO), ACGIH TLV-TWA is 50 ppm;
  - nitrogen dioxide (NO_2), ACGIH TLV-TWA is 3 ppm, ACGIH TLV-STEL (ceiling limit) is 5 ppm.

  NOTE: MSHA adopted 1972 ACGIH standards.

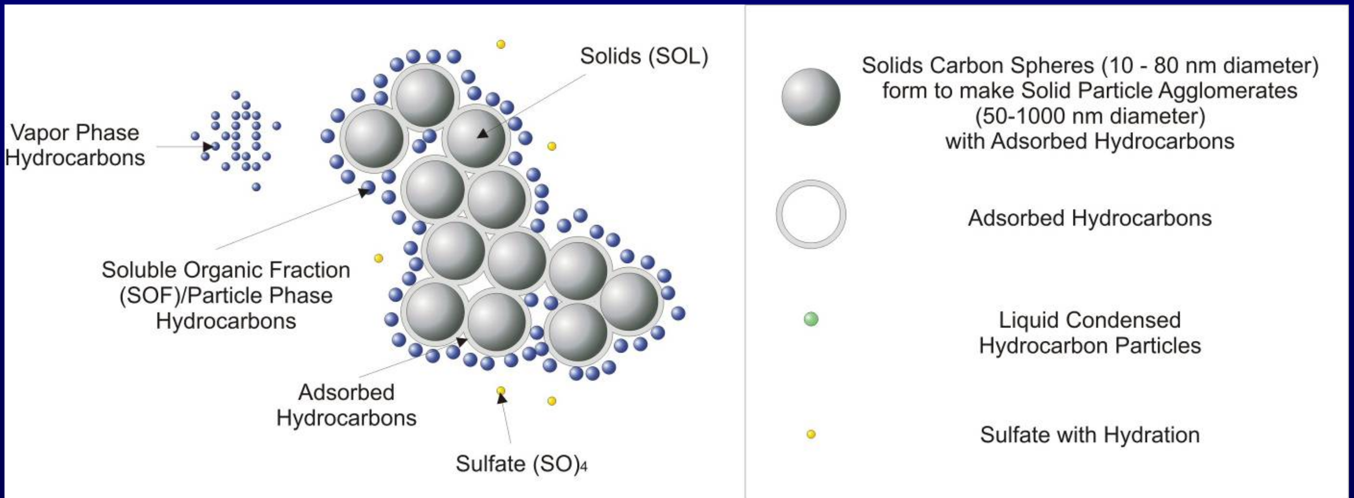
What is Diesel Particulate Matter (DPM)?

- Nano, ultrafine, and fine aerosols emitted by diesel engines are collectively known as DPM.

- DPM primarily consists of an aggregated core of nano and ultrafine carbonaceous particles (elemental carbon), surrounded by core-bound or suspended hydrocarbons (organic carbon).

- Inorganic components such as sulfates and ash also contribute to DPM.

- Physical and chemical composition of DPM are dependant on a number of physical and chemical processes occurring in an engine and in the atmosphere after their release.



Reducing Exposure of Underground Miners to Diesel Particulate Matter and Gases

Typical program on reducing exposure of underground miners to diesel particulate matter and gases have the following phases:

- Identification of the problem;
- Identification and establishing hierarchy of potential solutions;
- Institution and implementation of the program;

Identification of the Problem Through Monitoring Programs

- The problems should be identified and quantified using monitoring programs:
  - Ambient concentrations and exposure monitoring program:
    - Concentrations of particulate and gases in mine air;
    - Exposure assessment
  - Tailpipe emissions monitoring program:
    - DPM (EC)
    - CO, NO, and NO_2
- The monitoring should be continued throughout implementation phase of the program and the results should be used to constantly re-evaluate effectiveness of the program and adjust it accordingly.

Integrated Approach toward Comprehensive Solution

- The program should involve concerted efforts in areas of:
  - engine/vehicle/aftertreatment maintenance;
  - health and safety;
  - ventilation;
  - purchasing;
  - production…

  and
  - considerable support from company and mine management.

Success through Leadership

- The program needs a champion that has
  - adequate expertise, and
  - authority to manage and coordinate efforts within and throughout various mine organizational structures.

Exposure of underground miners to diesel particulate matter and gases can be effectively reduced using a multifaceted approach involving:

- Control of diesel emissions at their source:
  - Engine-out emissions;
  - Aftertreatment technologies.
- Control of airborne pollutants:
  - Ventilation;
  - Environmental cabs;
  - Personal protective equipment.
- Institution of administrative controls:
  - Better utilization and management of available resources;
  - No idling policy…

The most effective appears to be controlling diesel emissions at their source

- Reduction of engine-out emissions through:
  - Utilization of contemporary diesel engine technology;
  - Implementation of emissions assisted maintenance programs;
  - Utilization of alternative fuels.
- Aftertreatment technologies:
  - Retrofit applications;
  - OEM applications.

Contemporary Diesel Engine Technology

- Particulate emissions from modern diesel engines have been substantially reduced over the last couple decades.

- U.S. Environmental Protection Administration (EPA) nonroad engines 130 < kW < 560 (175 < hp < 750):
  - 1996 (Tier 1): PM = 0.54 g/kW-hr (0.40 g/hp hr);
  - 2003 (Tier 2): PM = 0.20 g/kW-hr (0.15 g/hp hr);
  - 2006 (Tier 3): PM = 0.20 g/kW-hr (0.15 g/hp hr);
  - 2011-2014 (Tier 4): = 0.020 g/kW-hr (0.015 g/hp hr).

Contemporary Diesel Engine Technology

- Tier 2 and Tier 3 engines achieve lower emissions by using some of the following tools:
  - high-pressure fuel injection with multiple injections per stroke;
  - increased peak cylinder pressures;
  - single-stage variable geometry turbocharger (VGT);
  - high-performance exhaust gas recirculation (EGR);
  - centrifugal closed crankcase ventilation…
- Tier 4 engines will have integrated advanced exhaust aftertreatment systems:
  - Diesel particulate filter systems and NO_x absorbers.

Engine Selection

- Engine replacement:
  - Lower emissions
  - Enabled implementation of advanced aftertreatment technologies

- Optimization of the application – engine, drive train, vehicle, and exhaust aftertreatment are integral parts of the system:
  - Lower emissions
  - Lower fuel consumption
  - Better performance
  - Enabled regeneration of DPF systems.

Optimization of Diesel Engines for Underground Mining Applications

- Confined space, limited ventilation, specific regulations
  - NO and NO_2 vs. NO_x

- Emissions at elevation over 5000 ft above see level

- Engine deration and recertification

- Optimization of advanced aftertreatment technologies

Optimization of Diesel Engines for Underground Mining Applications

- Underground coal mining permissible applications:
  - Surface temperature control;
  - Exhaust temperature control;
  - Intrinsically safe electronically controlled engine.

High requirements vs. relatively small market

Emission-Assisted Maintenance

- Emission-assisted maintenance vs. repair facility:
  - Emissions are used as diagnostic tools;
  - 250 hr PM;
  - Develop in house expertise;
  - Establish baseline and own criteria;
  - Prompt action…
- The objective is to maintain emissions at "new" (baseline) level.
- In-use emissions vs. certification emissions.

Alternative Fuel Formulations

- Biodiesel:
  - Yellow grease;
  - Soy biodiesel.

  Low sulfur content

  High oxygen content

  Lower energy content than #2 diesel

Alternative Fuel Formulations

- Water-in-diesel-fuel emulsions:
  - Hot-weather emulsion (77% #2 diesel, 20% water, 3% emulsifying agent).
  - Cold-weather emulsion (86% #2 diesel, 10% water, 2% methanol, 2% emulsifying agent).

  Lower energy content than #2 diesel

  Higher oxygen content

- Synthetic diesel (GTL):

  Extremely low sulfur content

  Extremely low content of aromatics

  High Cetane number

  Lower energy content than #2 diesel

Issues Related to Use of Alternative Fuels in Underground Mines

- Availability;
- Fuel supply management;
- Engine compatibility;
- Maintenance;
- Loss of engine power and efficiency;
- Secondary emissions;
- Compatibility with DPF systems;
- Cost…

Aftertreatment Technologies

- Control of gaseous emissions:
  - Diesel oxidation catalytic converters (DOCs) – CO and HC;
  - Selective catalyst reduction (SCR) – NO and NO_2.

- Control of DPM Emissions:
  - Diesel particulate filter (DPF) systems;
  - Filtration systems (FS) with disposable filter elements (DFE).
  - Flow trough filters

- Integrated systems

Selection of Aftertreatment Systems for Underground Mining Applications

- Selection of system type;
- Effects of systems on
  - concentrations of DPM (EC)
  - concentrations of regulated and unregulated gases.
- Regeneration/disposal;
- Installation, implementation, and maintenance issues;
- Cost benefit analysis.

Control of Airborne Pollutants

- Once released in the environment diesel pollutants miners exposure can be controlled by:
    - Ventilation;
    - Environmental cabs;
    - Personal protective equipment…

Ventilation

- Ventilation is traditionally used to control, flammable and explosive gases, other pollutant concentrations, and heat in underground mines.

- Diesel emissions control:
  - MSHA underground metal/nonmetal (30 CFR 57.5001, 1995).
    - 1973 ACGIH TLV TWA for CO, CO_2, NO, NO_2 and ceiling level for NO_2 .
  - MSHA underground coal :
    - ventilation rate (VR) and
    - particulate index (PI)
  - CANMET
    - CSA ventilation rates (EQI).
  - Ontario, 0.06 $m^3/s/kW$ (100 $ft^3/min/hp$).

Ventilation for Control of Diesel Emissions

- Quantities of air supplied per engine output (hp) in U.S. UG metal/nonmetal mines to dilute diesel emissions are generally lower then those in U.S. UG coal mines. Both are lower than quantities of air supplied per hp in Canadian UG metal mines.

- Controlling PM and gaseous emissions from diesel-powered equipment has became one of the major ventilation design factors;

- Quantities of air sufficient to dilute various pollutants are essential for overall quality of the air in production areas:
  - E.g. control of CO_2 and NO emissions from diesel engines.

Ventilation Issues

- Supplying sufficient quantities of fresh air to production areas presents particular challenge;
- Cascading ventilation is common practice;
- Problem of recirculation is particularly pronounced in large-opening mines;

Ventilation Cost

- Capital and operational costs of reducing miners' exposure to DPM by means of ventilation might be prohibitive:
  - Increase in ventilation rate linked to increase in power requirement for the fans and consequently increase in energy consumption.

Environmental Cabs

- Air filtration/heating/air conditioning system:
  - Filter media needs to be designed to remove DPM (HEPA filters).
- Cab integrity:
  - Positive inside pressure (~100 Pa).
- If properly designed and maintained, protects operator from DPM, dust, noise but does not provide protection to workers outside the cab.

Environmental Cabs

- Issues:
  - Capital cost of acquiring cab;
  - Operational costs;
  - Reduced visibility;
  - Space requirements for retrofit applications;
  - Human factor
  - CO, CO_2, NO, and NO_2

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Personal Protective Equipment (PPE) for DPM: Underground Metal/Nonmetal Mines

- Air purifying respirator with:
  - HEPA filter certified by NIOSH under 30 CFR Part 11, or
  - filter certified by NIOSH under 42 CFR Part 84 as 99.97%efficient, or
  - filter certified by NIOSH for DPM.

- Non-powered, negative pressure, air purifying, particulate filter respirators with:
  - R- or P-series filter, or
  - any filter certified by NIOSH for DPM.

Personal Protective Equipment (PPE) : Underground Metal/Nonmetal Mines

- PPE should supplement engineering and administrative controls only when those are found unfeasible or insufficient.
- Respirator fit test is crucial.
- CO, CO_2, NO, and NO_2 ???

Education

- Awareness of potential health effects related to exposure to diesel particulate matter and gases.

- Knowledge of general instituted strategies and their individual role in those - OWNERSHIP.

- Knowledge of implemented technologies.

Summary

- Controlling underground miners' DPM exposure and implementing DPF systems in underground mines require multifaceted approach.
- The integrated approach should be used to develop elaborate program.
- The success will depend on concerted effort throughout mine organizational structure and considerable support from mine management .
- The program should be headed by a champion with adequate expertise and authority.
- The strategies and technology should be selected after comprehensive consideration of all available options and cost benefit analysis.

Summary (2)

- Hierarchy of strategies should he established and adequately instituted.
- Implementation issues should be rather part of design process then afterthought.
- The monitoring results should be used to constantly re-evaluate effectiveness of the program and adjust it accordingly.
- Education of all players should facilitate implementation of the program.

Thank you for your attention!!!

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