The Role of DPM Loading on the Filtration Process in DFEs and DPFs

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Introduction

- Clean uncoated ceramic oxides and SiC monolith diesel particulate filters (DPFs) are on average approximately 75% - 95% efficient in filtering solid diesel aerosols of all sizes [*Lorentzou et al. 2008, Dabhoiwala et al. 2009, Yang et al. 2009*].
- The clean wall flow monoliths were found to preferentially filter solid particles of certain sizes [*Yang et al. 2009*]:
  - The filtration efficiency is higher for particles with D_{50} < ~ 80 nm) and for particles with D_{50} > ~ 200 nm) from typical diesel spectrum, and is relatively low for particles with D_{50} ~ 100 nm.
- The lowest efficiency for clean uncoated filters is found for aerosols with diameters between 200 and 400 nm [*Lorentzou et al. 2008*].

- Lorentzou S, Pagkoura C, Konstandopoulos AG, Boettcher J [2008]. Advanced catalyst coatings for diesel particulate filters. SAE Technical Paper 2008-01-0483.
- Dabhoiwala RH, Johnson JH, Naber JD [2009]. Experimental study comparing particle size and mass concentration data for a cracked and uncracked diesel particulate filter. SAE Technical Paper 2009-01-0629.
- Yang J, Stewart M, Maupin G, Herling D, Zelenyuk A [2009]. Single wall diesel particulate filter (DPF) filtration efficiency studies using laboratory generated particles. Chemical Engineering Science 64, 1625-1634.

Introduction

- The cake formed from diesel particulate matter (DPM) accumulated in the channels and on the surfaces of filters plays an important role in DPM filtration process.
- The effects of DPM cake on the filtration process is most extensively studied for ceramic monoliths in DPFs.
- The clean wall flow DPF primarily exhibit so-called deep-bed filtration mode, while loaded DPF exhibit so-called cake filtration mode [*Schmidt et al. 2007, Konstandopoulos and Papaionnou 2008*].

- Schmidt N, Root T, Wirojsakunchai E, Schroeder E, Kolodziej C, Foster DE, Suga T, Kawai T [2007]. Detailed diesel exhaust particulate characterization and DPF regeneration behavior measurements for two different regeneration systems. SAE Technical Paper 2007-01-1063..
- Konstandopoulos AG, Papaioannou E [2008]. Update on the science and technology of diesel particulate filters. KONA Powder and Particle Journal 26, 36-65.
- Frey M [2005]. Study of a sintered metal diesel particulate trap. SAE Technical Paper 2005-01-0968.

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Introduction

- The filtration process in the DPF made of sintered metal sheets resembles that found in wall flow monoliths, with discernable deep-bed filtration and cake filtration phases [*Konstandopoulos et al. 2005*].
- The information on the filtration process in disposable filter elements (DFEs) is rather limited [*Colamussi 2008*].
- The efficiency of DFE loaded with soot is substantially better than that of a new element [*Colamussi 2008, Bugarski et al. 2009*].

- Konstandopoulos AG, Vlachos N, Stavropoulos I, Skopa S, Schumacher U, Woiki D, Frey M [2005]. Study of a sintered metal diesel particulate trap. SAE Technical Paper 2005-01-0968.
- Colammusi A [2008]. Disposable filters. In Particle Filter Retrofit for all Diesel Engines. Publisher Brill Ulrich, Editor Mayer Andreas. Haus der Technik Fachbuch Band 97, ISBN 978-3-8169-2850-8.
- Bugarski AD, Schnakenberg GH Jr, Hummer JA, Cauda E, Janisko SJ, and Patts LD [2009]. Effects of diesel exhaust aftertreatment devices on concentrations and size distribution of aerosols in underground mine air. Env Sci Tech 43, 6737-6743.

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Introduction

- Growth of fully developed DPM cake appears to be insensitive to the type of underlining filter media. [*Konstandopoulos et al. 2005*].
- Even at a very low DPM load, the DPF with formed DPM cake reduces concentration of particles by two-to-three orders of magnitude further than the clean element [*Lorentzou et al. 2008*].
- After cake is formed, the solid particle efficiency for DPFs [*Yang et al. 2009*] and DFEs [*Colamussi 2008*] for all particle sizes is reported to be higher than 99%.

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Introduction

- Due to issues with repeatability and reproducibility, characterization of the effects of filter cake on emissions of nucleation mode aerosols is rather challenging.
- In general, data available in the literature on nucleation mode aerosols is inconclusive.

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Objective

- Investigate effects of DPM loading on concentration and size distribution of diesel aerosols in mine air for various filtration systems:
  - Filtration systems with three different high-temperature disposable filter elements (DFEs):
    - DFE-A,
    - Laundered DFE-A (LDFE-A), and
    - DFE-B
  - Two diesel particulate filter (DPF) systems:
    - uncatalyzed system with Cordierite element, and
    - electrically regenerated system with sintered metal (SM) elements followed by diesel oxidation catalyst (DOC)

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Methodology

- The investigation is conducted using data generated at the NIOSH Diesel Laboratory at Lake Lynn Experimental Mine (DL at LLEM)
- More information on DL at LLEM and methodology is available in the literature [Bugarski et al. 2007, Bugarski et al. 2008, Bugarski et al. 2009].

- Bugarski AD, Schnakenberg GH Jr, Hummer JA, Cauda E, Janisko SJ, and Patts LD [2007]. Examination of Diesel Aftertreatment Systems at NIOSH Lake Lynn Laboratory. 13th Annual MDEC, Richmond Hill, ON, October 1-5.
- Bugarski AD, Cauda E, Janisko SJ, Patts LD , Hummer JA,, Mischler S [2008]. Evaluation of an Electrically Regenerated Sintered Metal Diesel Particulate Filter System in Underground Mine Laboratory. 14th Annual MDEC, Richmond Hill, ON, October 6-10.
- Bugarski AD, Schnakenberg GH Jr, Hummer JA, Cauda E, Janisko SJ, and Patts LD [2009]. Effects of diesel exhaust aftertreatment devices on concentrations and size distribution of aerosols in underground mine air. Env Sci Tech 43, 6737-6743.

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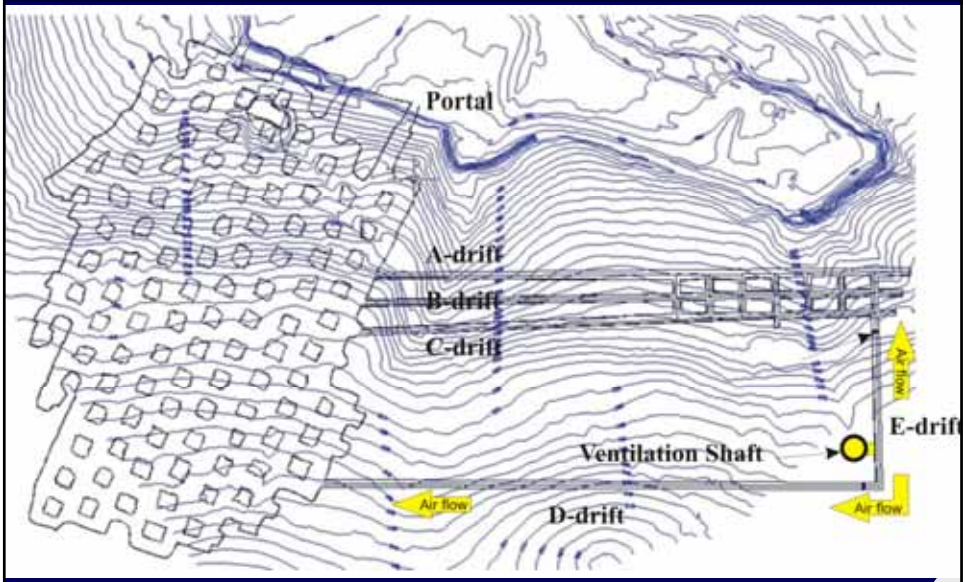
NIOSH Diesel Laboratory is located at D-drift of Lake Lynn Experimental Mine (DL at LLEM)



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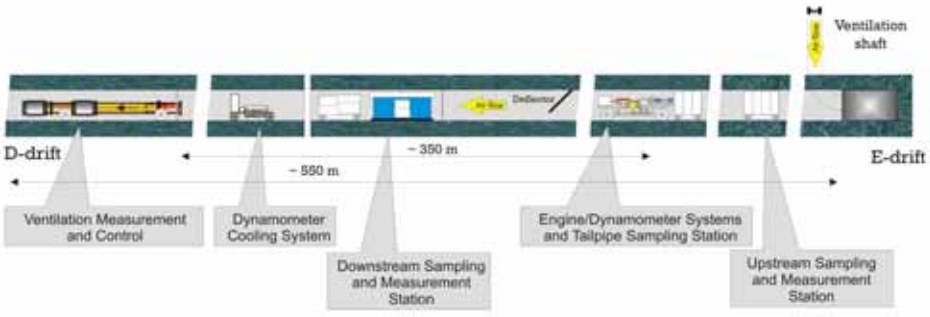
The NIOSH DL at LLEM consists of engine/dynamometer system, two sampling/measurement stations, and a ventilation system. This system is integrated with the LLEM ventilation system.



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Filtration systems with three different high-temperature disposable filter elements (DFEs), DFE-A, LDFE-A, and DFE-B, were tested using an air-to-air heat exchanger to cool the exhaust.

Air-to-air heat exchanger

Filter canister

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Cordierite DPF systems were tested after regeneration using an off-board electrical regeneration station.
The three banks of SM DPF system were sequentially regenerated using on-board electrical heaters.

Cordierite DPF

Electrically regenerated SM DPF

DOC

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The test engine (Isuzu C240), fueled by ultra-low sulfur diesel (ULSD), was operated over steady-state test modes (part of 8-mode ISO 8178 C1 test cycle).

Mode	Description	Engine Speed	Torque	Power
		rpm	Nm	kW
R50	Rated speed 50% load	2950	55.6	17.2
R100	Rated speed 100% load	2950	111.2	34.3
I50	Intermediate speed 50% load	2100	69.1	14.9
I100	Intermediate speed 100% load	2100	136.9	30.6

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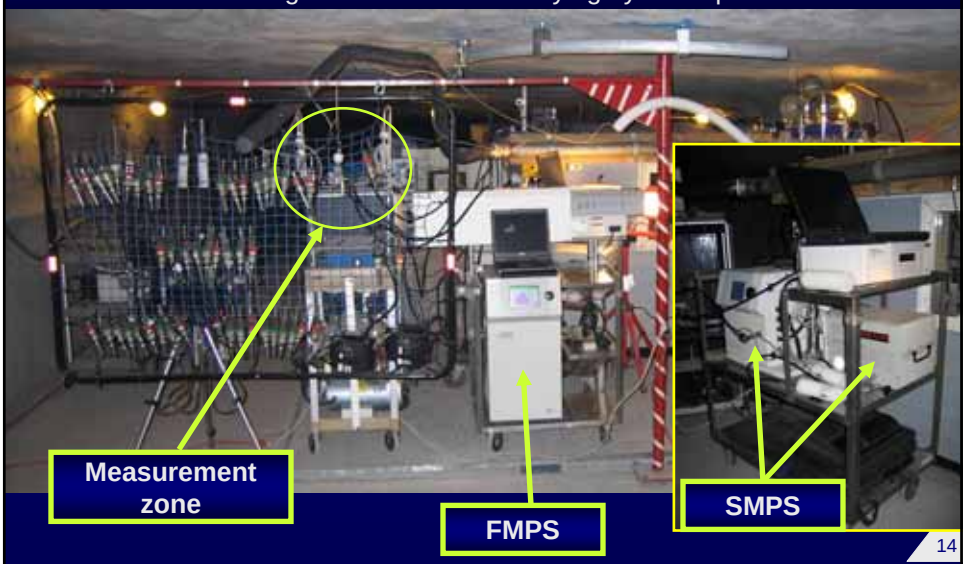
Scanning Mobility Particle Sizer (SMPS) and Fast Mobility Particle Sizer (FMPS) from TSI Inc. were used at a downstream measurement station.
The SMPS was used at upstream measurement station.
FMPS has advantage over SMPS for studying dynamic processes.



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Results and Discussion

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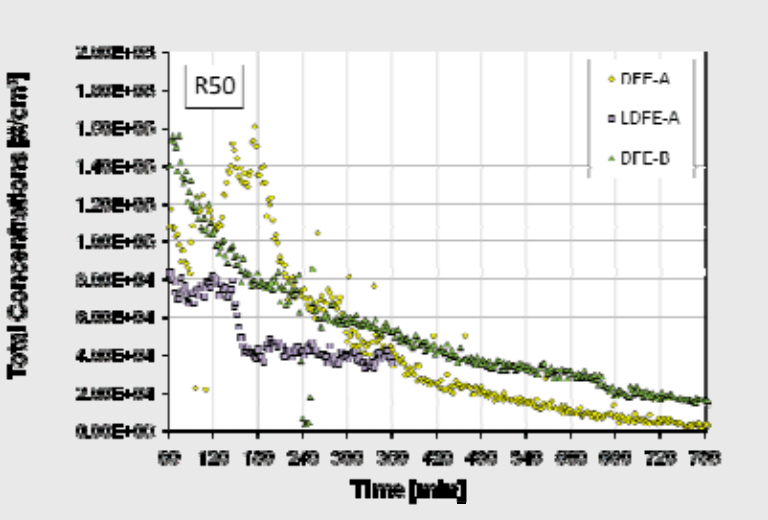
Background corrected total number concentrations of aerosols in mine air during tests of three types of HT DFEs gradually decreased with accumulation of DPM in DFEs.



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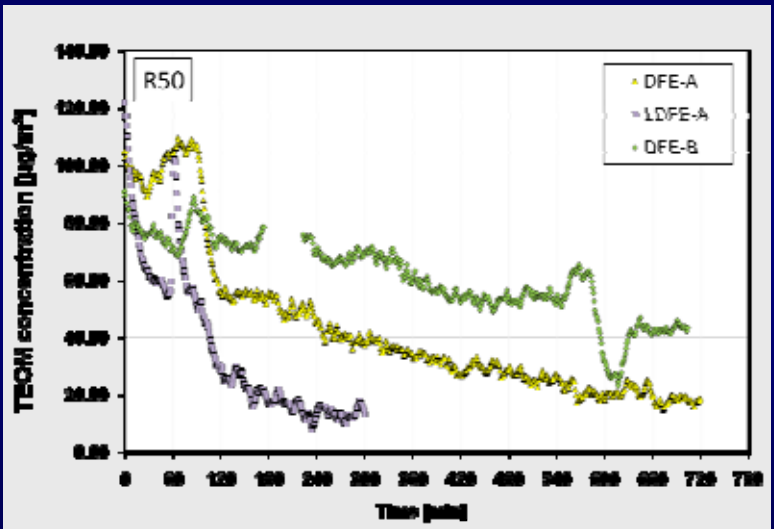
Background corrected total mass concentrations of aerosols in mine air during the same tests gradually decreased with accumulation of DPM in DFEs.



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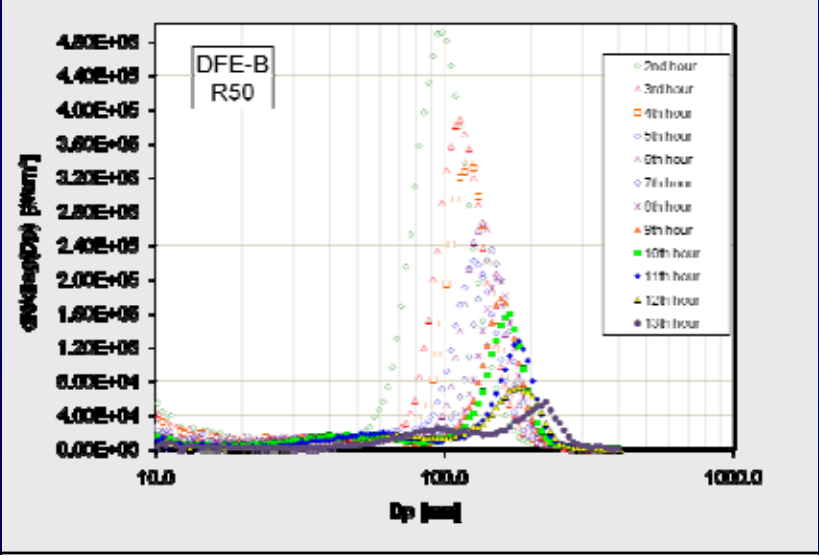
Those results are corroborated by results of size distribution measurements.
For DFE-B at R50 conditions, the median electrical mobility diameter ($_{50}D_{em}$) of aerosols increased and total concentrations decreased with DPM accumulation.



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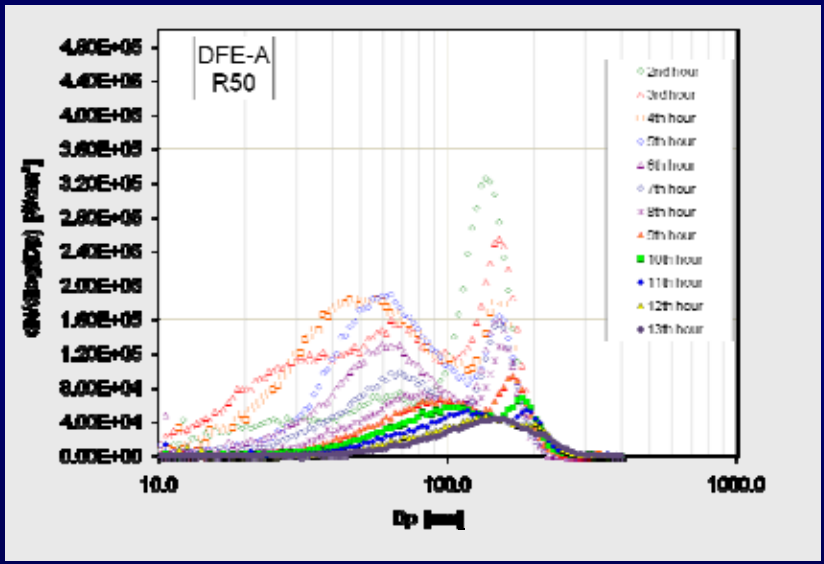
Average size distributions of aerosols in mine air also dramatically changed throughout the test of DFE-A at R50 conditions. The background concentrations, which were substantially higher during DFE-A than during DFE-B test, impacted the results.



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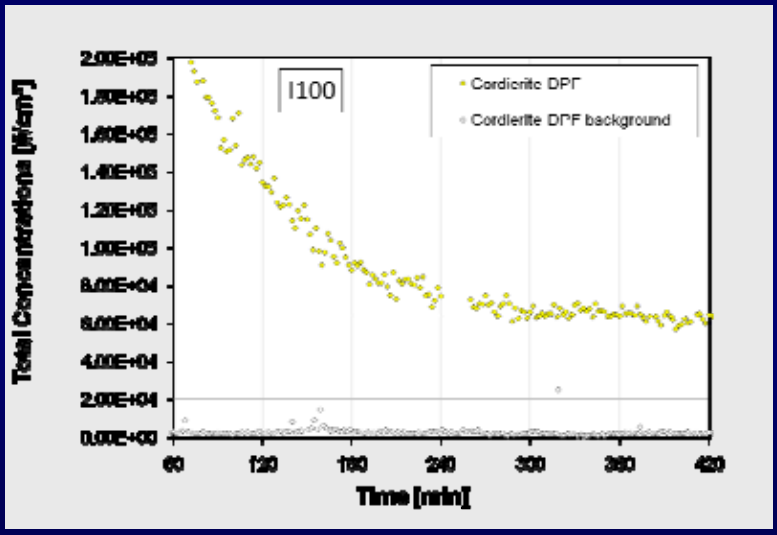
Similarly, total number concentrations of aerosols in mine air during test of the Cordierite DPF system decreased gradually with accumulation of DPM in filter media.



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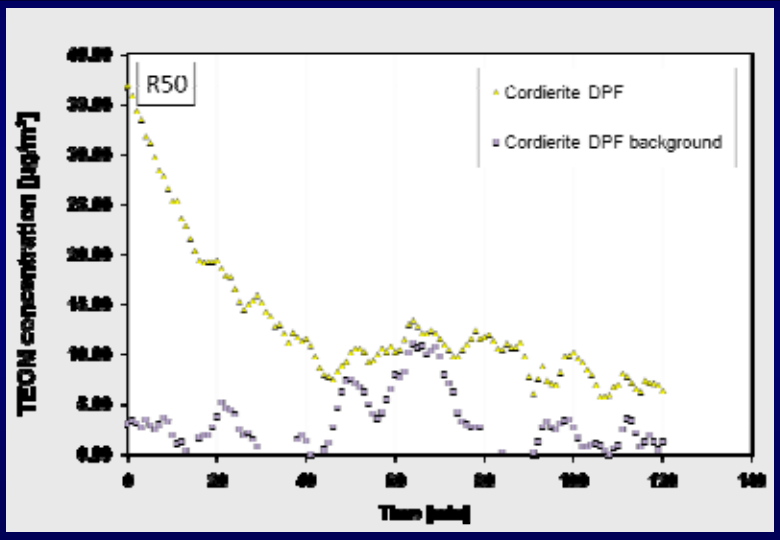
Total mass concentrations of aerosols in mine air during a similar test (only 120 min) of Cordierite DPF decreased with accumulation of DPM in DPF.



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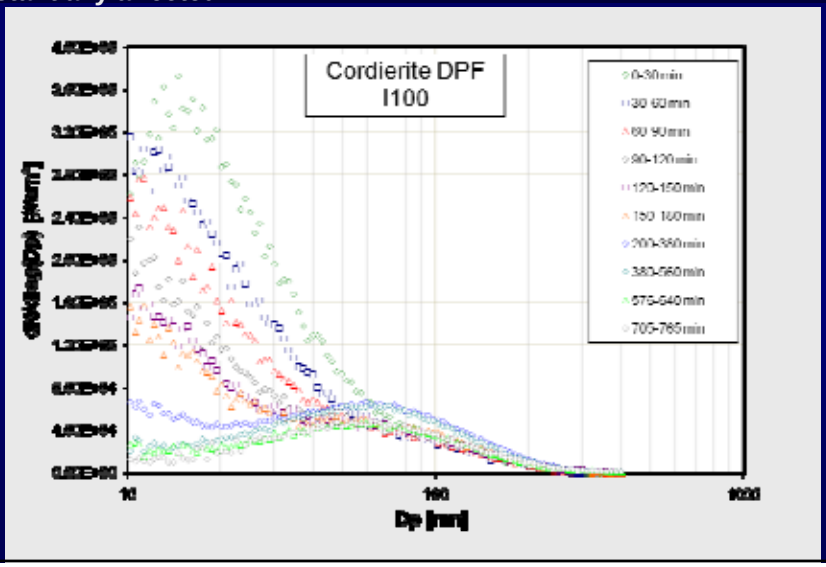
For Cordierite DPF tested at I100 conditions, the concentrations of nucleation mode aerosols gradually decreased with accumulation of DPM in the media.
The distribution of accumulation aerosols does not appear to be substantially affected.



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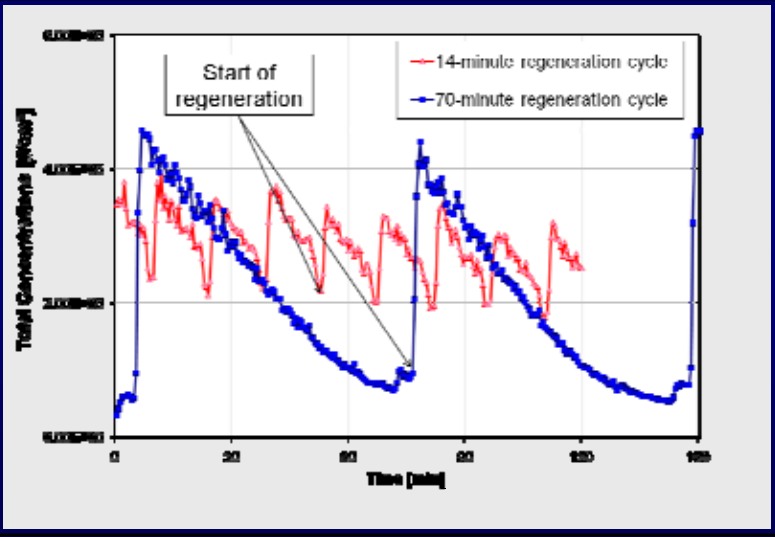
In the case of SM DPF, the regeneration process (removal of DPM) from media resulted in transient nature of aerosol emissions.
For R50 conditions, total number concentrations of aerosols in mine air (measured by FMPS) increased dramatically after regeneration and gradually decreased with accumulation of DPM in the filter media.



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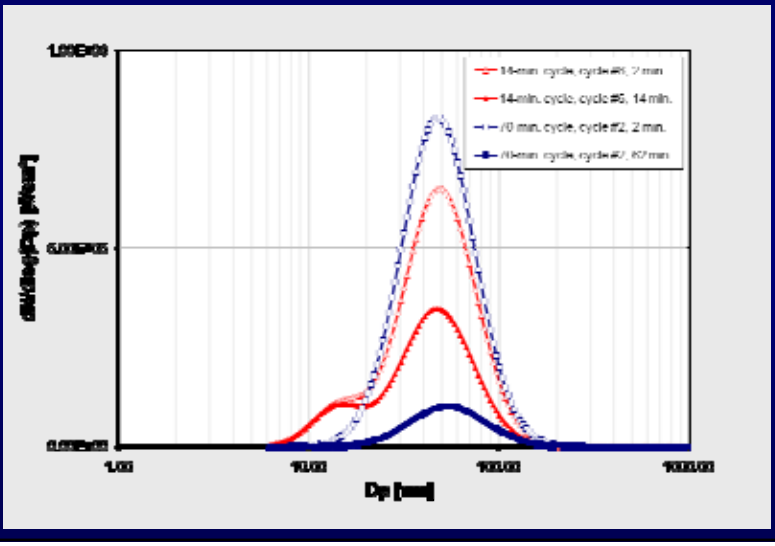
The accumulation of aerosols in the media results in lower peak concentrations of aerosols at the end than at the beginning of the regeneration cycle.
The $_{50}D_{em}$ of aerosols during R50 does not appear to be significantly affected (except for a hint of nucleation mode for 14-min cycle).



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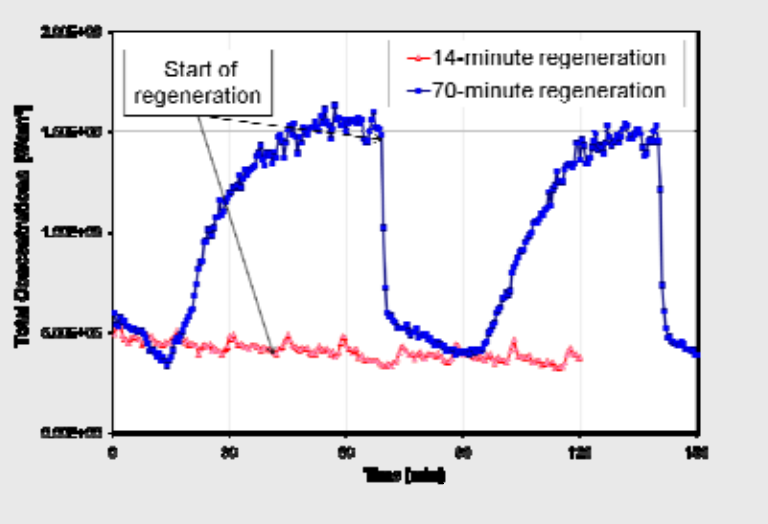
For R100 conditions, total number concentrations of aerosols (FMPS) in mine air during the test of electrically regenerated SM DPF decreased dramatically with 70-min. regeneration and increased gradually with accumulation of DPM in DPF.



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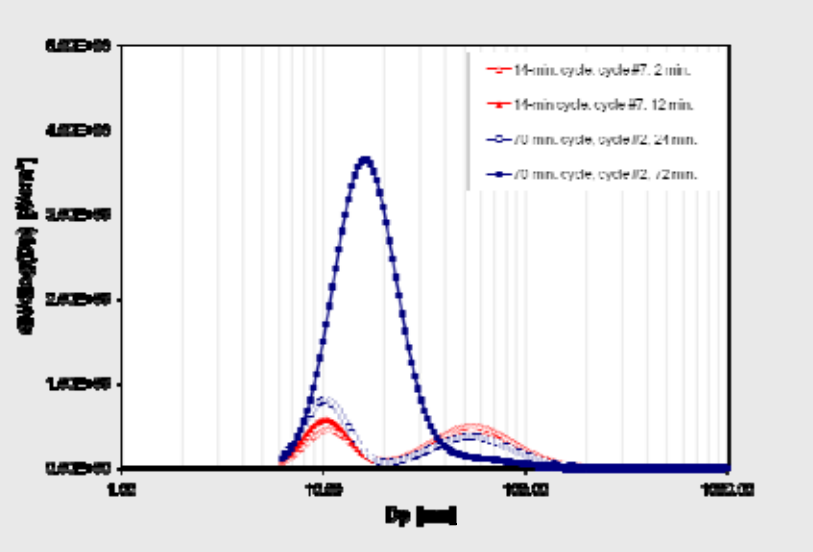
For R100 conditions during the 70-min. regeneration cycle, size distribution measurements showed a gradual increase in number of nucleation mode particles and decrease in number of accumulation mode particles after the electrical regeneration of SM DPF.



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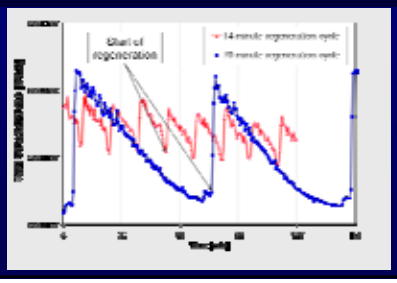
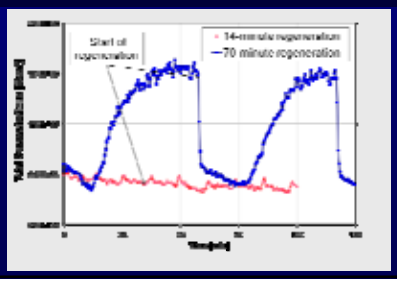
For both conditions, the length of the regeneration cycle and the amount of accumulated DPM had significant effect on concentrations.

For R50 conditions, more DPM accumulated during a longer regeneration cycle resulting in lower concentrations at the end of cycle.

On the contrary, for R100 conditions, more DPM accumulated during a longer regeneration cycle resulting in higher concentrations at the end of cycle (nucleation mode aerosol formation as a function of higher exhaust temperature).

Based on higher concentrations after regeneration, it appears that more complete regeneration occurs during a longer regeneration cycle for both conditions.





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Conclusion

- In general, the data generated in this study corroborate with data published in the literature on the effects of accumulated DPM in filtration systems on mass and number concentration of solid particles (accumulation mode particles) emitted by diesel engines equipped with DPFs and DFE filtration systems.
- However, the data generated in this study show that the effects of filtration systems on number and distribution of actual diesel aerosols with complicated physical and chemical makeup is not easy to generalize.
- The makeup of the DPM, such as presence of high concentrations of semi-volatile and volatile organic species and other precursors to nucleation mode aerosols, exhaust temperature, and ambient conditions are some of the parameters affecting concentration of diesel aerosols in the environment.

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Conclusion

- The data showed that emissions from DFEs and DPFs exhibit some fundamental differences.
  - The accumulation of DPM in the DFE media results in changes in concentrations of both nucleation and accumulation mode aerosols.
  - Formation of DMP cake in DPF media appears to primarily affect nucleation mode aerosols.
- Since trapped DPM plays a major role in the filtration process, the effectiveness of filtration systems , and ultimately the level of protection to the workers provided by those systems, is a function of the amount of DPM present in the filter.
- Amount of DPM present in the filter, length of the test, engine PM emissions, regeneration frequency and intensity, and a number of other factors affect the results of testing of filtration systems and should be considered when results of efficiency measurements are assessed.
- Further research is needed to provide more insight in the issue.

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