Field Evaluation of Sintered Metal Filter Systems at Nickel Mine

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Sintered metal diesel particulate filter (DPF) systems supplied by Mann+Hummel (Model SMF®-AR) are installed on two light-duty vehicles from Vale's Creighton Mine.

5109	
vehicle type	forklift
vehicle manufacturer	Kubota
vehicle model	R520SF
engine manufacturer	Kubota
engine model	V2203-M-ES
number of cylinders	4 (inline)
engine displacement	2.2 l
engine type	liquid cooled, naturally aspirated
engine output	36 kW (49 hp)

368	
vehicle type	10 ton locomotive
vehicle manufacturer	Clayton Equipment Ltd.
engine manufacturer	Deutz Corporation.
engine model	F6L912W
number of cylinders	6 (inline)
engine displacement	6.1 l
engine type	air cooled, naturally aspirated
engine output	60 kW (80 hp)

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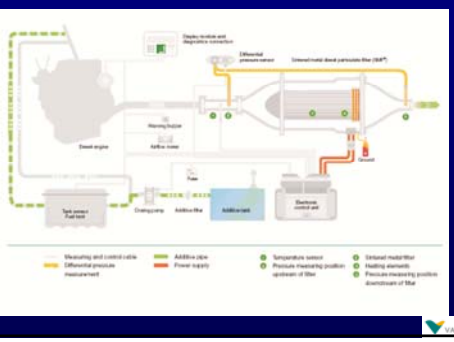
Mann+Hummel SMF® -AR is actively regenerated system.

- These systems are built around filter elements made of sintered metal plates.
- When needed, the electrical heater mounted at the back of the filter element can be used to actively regenerate the system.
- Iron-based fuel additives (DT7 (Satacen® 3) or DT8i (Satacen®)) supplied by on-board dosing system play important role in regeneration process and operation of the system.



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SMF® -AR systems (used with DT7 (Satacen® 3) were subjected to long-term evaluation at Vale's Creighton Mine.

- The results of 1500+ hours of evaluation of SMF systems installed on forklift 5109 and loco 368 and operated with DT7 (Satacen® 3) fuel additive were previously reported in the literature and the last year MDEC conference:
  - Stachulak JS, Hensel V [2010]. Successful application of DPF system at Vale Inco's Creighton Mine. In: Hardcastle S and McKinnon DL Eds. Proceedings of 13th U.S./North American Mine Ventilation Symposium.
  - Stachulak JS, Hensel V [2010]. Successful evaluation of DPF system at Creighton Mine. 16th Annual MDEC Conference.

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After initial evaluation is completed, the new set of SMFs was installed on forklift 5109 and loco 368 and DT7 (Satacen® 3) fuel additive is replaced with EPA approved DT8i (Satacen®) fuel additive, the series of emissions tests was conducted to assess the effects of these systems on aerosol and gaseous emissions.

- The emissions testing was done by NIOSH and Vale at surface shop of Creighton Mine.
- The emissions of tested vehicles/engines were assessed for three engine operating conditions:
  - hydraulic stall (HS),
  - high idle (HI), and
  - low idle (LI).

Engine Speed [rpm]	Forklift 5109/ Kubota V2203-M-ES	Loco 368 / Deutz F6L912W
HS	2160	2800
HI	2240	3100
LI	760	1000

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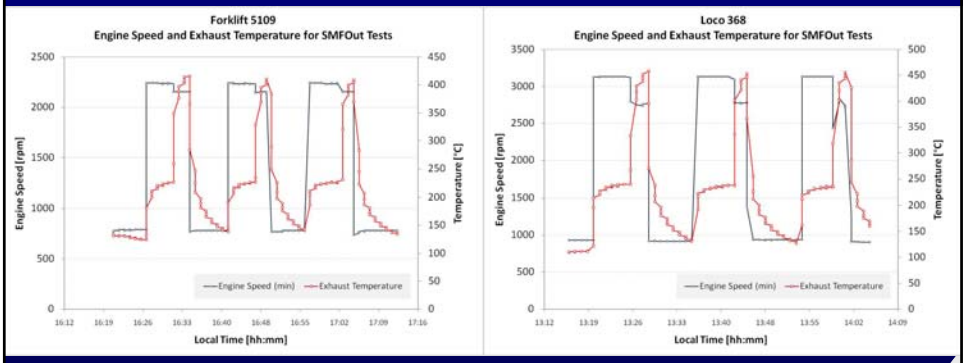
The effects of SMF systems were assessed using the results of sequential measurements performed on the exhaust drawn from the ports located upstream and downstream of the SMF systems installed on forklift 5109 and loco 368.

The measurements at each location were performed sequentially for three series of four-minute HI and LI test, and two-minute HS test (LI 1, HI 1, HS 1, LI 2, HI 2, HS 2, LI 3, HI 3, HS 3).



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The effects of the systems on concentrations of criteria (CO, CO_2, NO, and NO_2) and other gases were determined using results of measurements made in undiluted exhaust using FTIR analyzer (Gasmet, Model 4000).

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Aerosol measurements were performed on the exhaust diluted using partial dilution system (Dekati, Model FPS4000).

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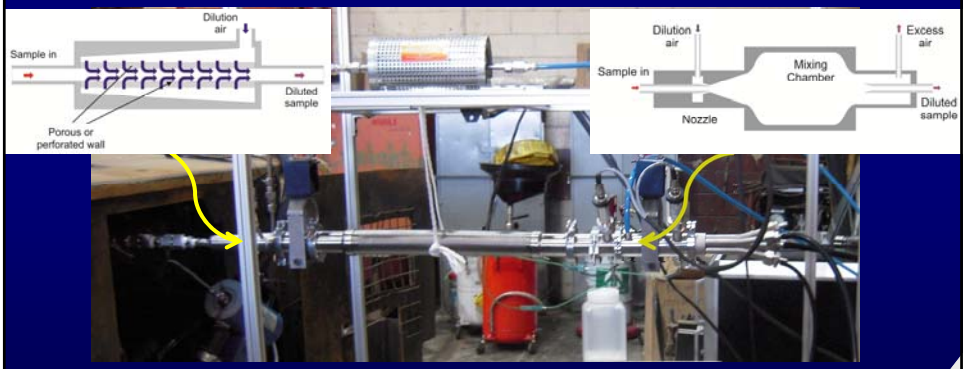
Dekati FPS4000 is designed to dilute exhaust in two stages.

- Primary dilution occurs in perforated disk diluter;
- Secondary dilution provided by ejector diluter;
- The residence chamber was inserted between those two stages.



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Concentrations and size distributions of aerosols in the exhaust diluted by partial dilution system were measured using Fast Mobility Particle Sizer (TSI, Model 3091 FMPS).

Surface area of aerosols deposited in alveolar region of human lungs was measured in exhaust diluted by partial dilution system using Nanoparticle Surface Area Monitor (TSI, Model 3550 NSAM).

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Results:
Concentrations of CO_2, CO, NO, NO_2, and NO_X (FTIR)

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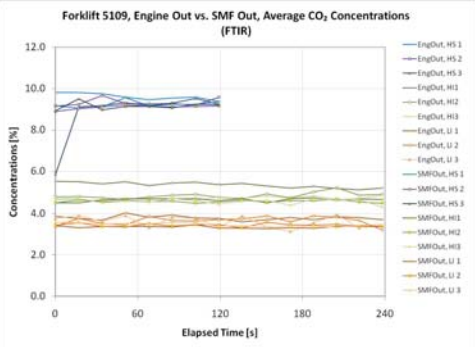
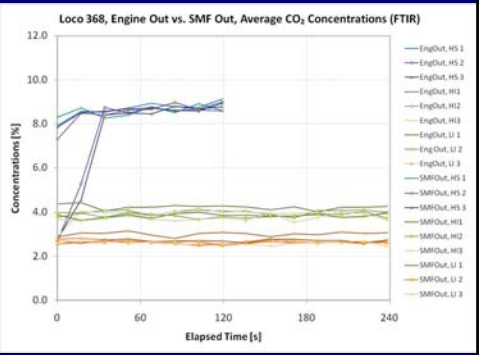
The FTIR is used to measure gaseous emissions upstream and downstream of SMF systems installed on forklift 5109 and loco 368.





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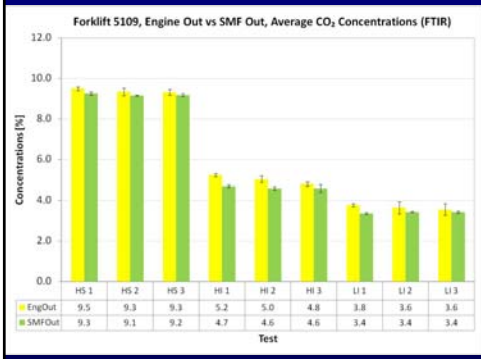
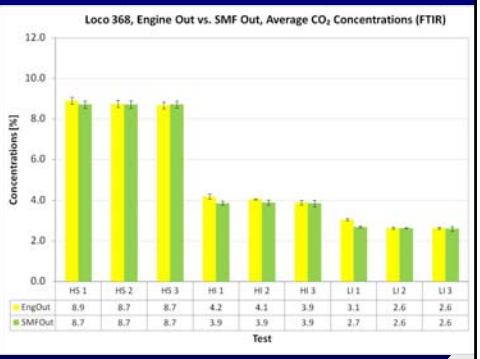
The results of FTIR measurements performed during the last minute of each test were used to calculate average CO, CO_2, NO, NO_2, and NO_X concentrations.
The analysis of CO_2 results indicates the following:

1. Hydraulic stalls (HS) performed on the forklift 5109 and loco 368 produced fairly high loads for the engines in those vehicles;

2. The repeatability of engine operating conditions indicated by CO_2 results allow for direct comparison of the results of emission measurements.





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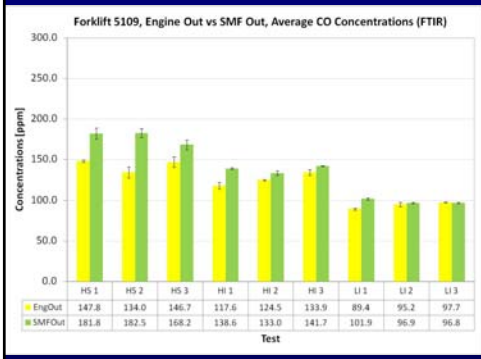
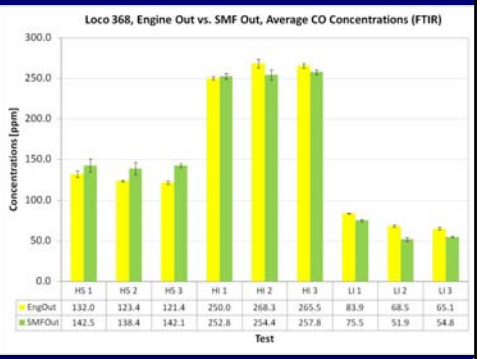
The average CO concentration results indicate the following:

1. The effects of SMF systems on CO emissions are relatively minor, in a number of the cases those are within accuracy limits of the method;

2. Higher "SMF out" CO emissions measured for HS conditions potentially indicate spontaneous regeneration of the SMF elements . At HS conditions the exhaust temperatures for forklift 5109 and loco 368 were 400°C and 450°C, respectively.





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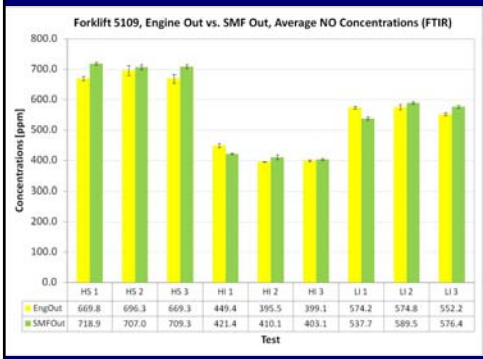
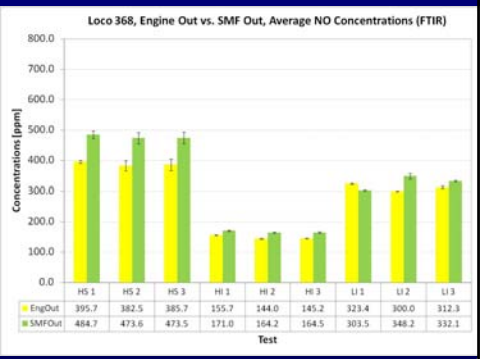
The NO concentrations indicate the following:

1. The effects of SMF systems on NO emissions are relatively minor, in the majority of the cases within accuracy limits of the method;

2. The exception were higher "SMF out" NO emissions measured for HS conditions. Those can be potentially linked to spontaneous regeneration of SMF elements.





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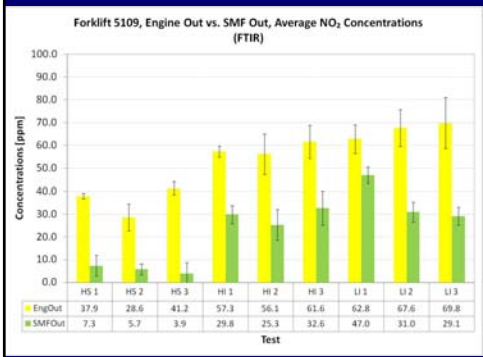
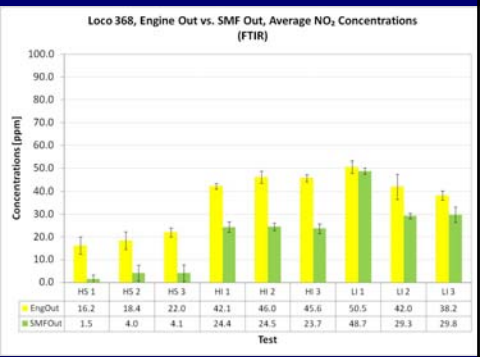
Analysis of average NO_2 concentrations indicate the following:

1. The substantial fraction of NO_2 is consumed in reaction with soot stored in SMF element;
2. That fraction is the highest for HS conditions.





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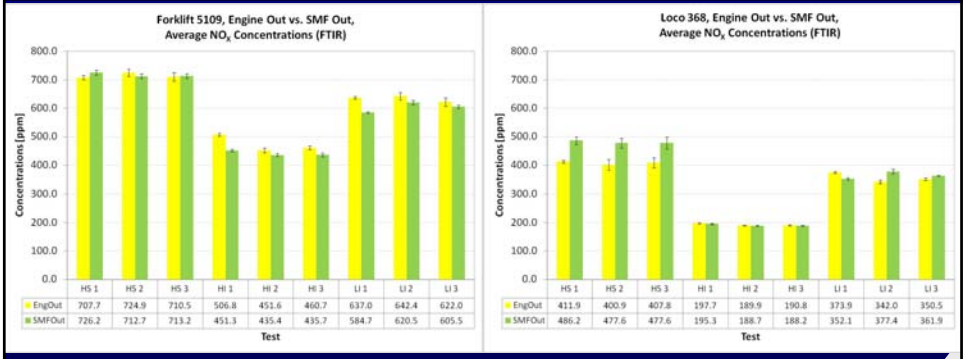
The results of NO and NO_2 measurements were also used to calculate average NO_X concentrations.

The NO_X results indicate the following:
1. The effects of SMF systems on NO_X emissions are relatively minor, in the majority of the cases within accuracy limits of the method;

2. The exception are higher "SMF out" NO_X emissions for HS conditions that can be potentially linked to spontaneous regeneration on SMF element.



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Results:
Number Concentrations and Size Distributions (FMPS)

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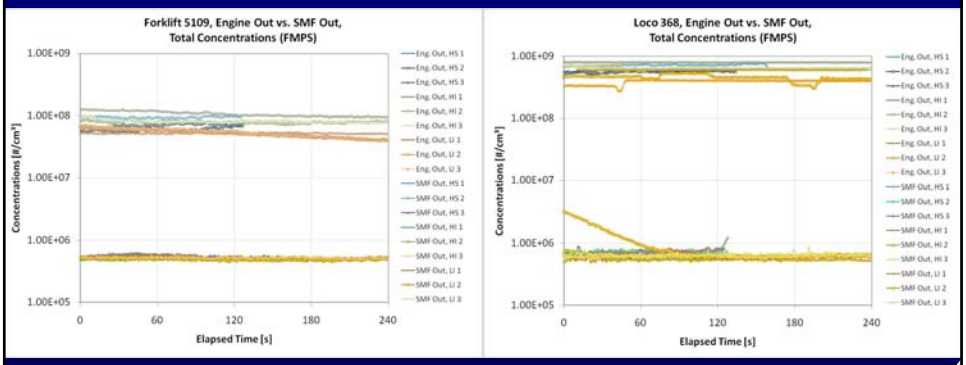
Simultaneously with FTIR measurement, the concentrations and size distributions of aerosols were measured using FMPS.

The measurements were performed in the diluted exhaust drawn from exhaust of the forklift 5109 and loco 368, upstream and downstream of SMF system.

To obtain aerosol concentrations, the FMPS concentrations were multiplied by test specific average dilution ratio.



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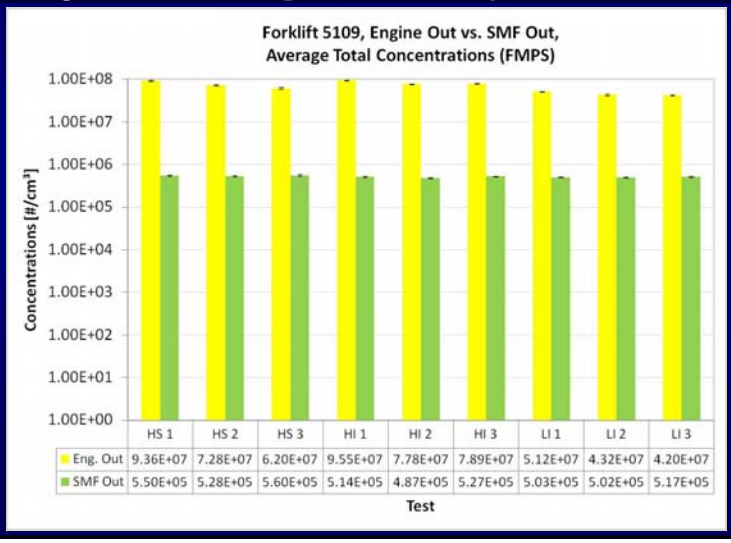
The dilution-corrected FMPS results for measurements performed during the last minute of each test were used to calculate average concentrations.

The concentrations downstream of the SMF system installed on the forklift 5109 were found to be approximately two order of magnitude lower than corresponding concentrations upstream of SMF system.



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Similarly, the concentrations downstream of the SMF system installed on the loco 368 were found to be approximately three order of magnitude lower than corresponding concentrations upstream of SMF system.

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When compared with corresponding number concentrations measured upstream of those systems, the number concentrations measured after SMF systems were found to be at least 80 times lower.

Test	Forklift 5109, Reductions [%]	Loco 368, Reductions [%]
HS 1	99.4	99.9
HS 2	99.3	99.9
HS 3	99.1	99.9
HI 1	99.5	99.9
HI 2	99.4	99.9
HI 3	99.3	99.9
LI 1	99.0	99.9
LI 2	98.8	99.9
LI 3	98.8	99.8

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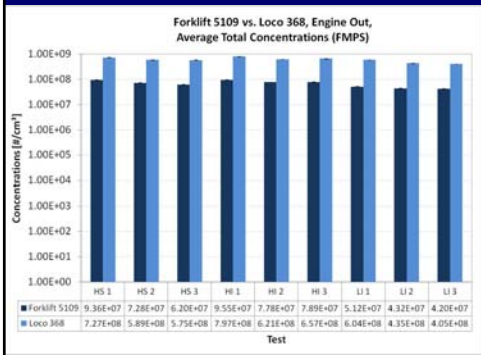
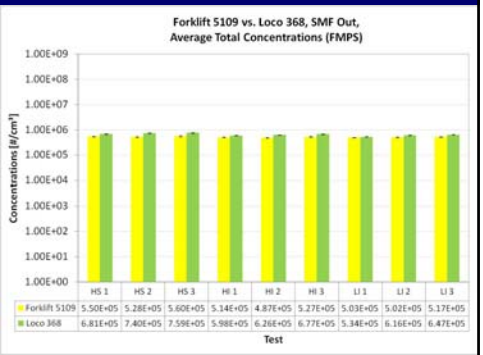
The difference in efficiency numbers for those two systems can be explained by the fact that the loco 368 engine emitted approximately one order of magnitude higher concentrations of aerosols than the forklift 5109 engine while the concentrations of aerosols at the outlet of SMF systems installed on both of those engines were at the same order of magnitude.





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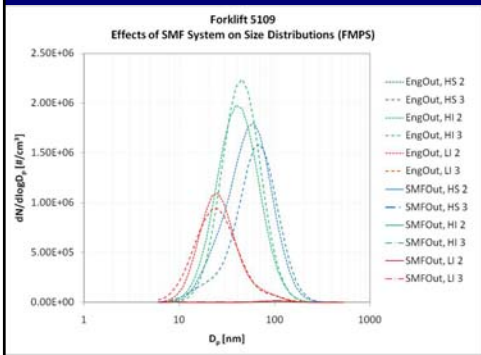
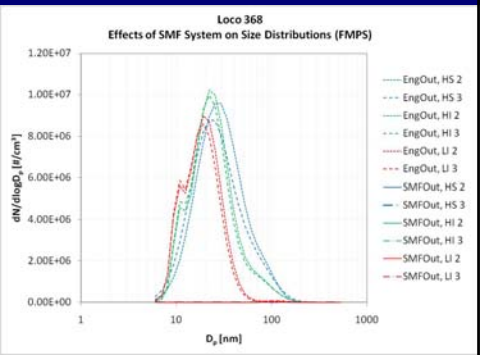
The FMPS measurements showed that the SMF systems installed on both vehicles/engines not only dramatically reduced concentrations, but also changed size distributions of aerosols.

If shown on the same linear scale as the engine-out size distributions, the size distributions of aerosols emitted from SMF systems are almost unnoticeable.





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Forklift 5109:

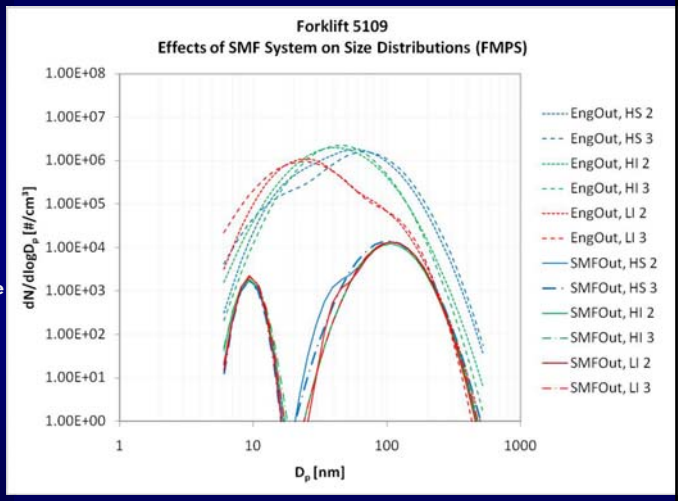
The size distributions of aerosols emitted by the engine were single modal or bimodal, depending on engine operating conditions.

For HS and HI conditions the majority of the aerosols were distributed in accumulation mode with average median diameter ranging from 59 to 96 nm.

In LI case, the majority of the aerosols were found in nucleation mode with average median diameter of app. 24 nm

The SMF-out size distributions were bimodal or trimodal, depending on engine operating conditions.

The majority of the aerosols were distributed in accumulation mode with average median diameter ranging from 102 to 109 nm.



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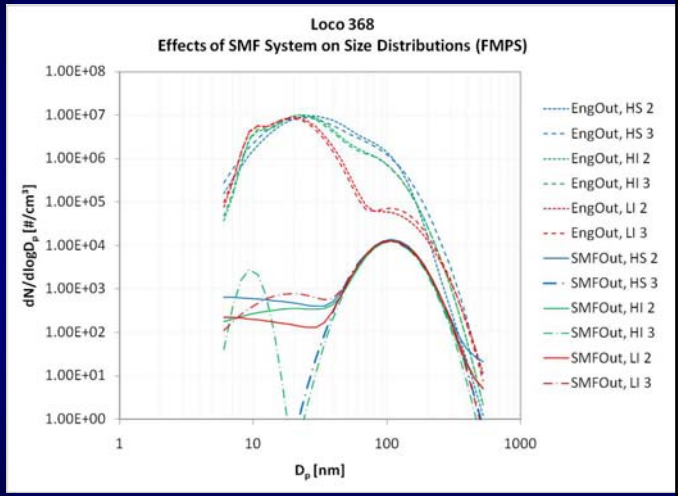
Loco 368:

The size distributions of aerosols emitted by the engine were bimodal or trimodal, depending on engine operating conditions.

For all conditions the majority of the aerosols were distributed in nucleation mode with average median diameter ranging from 19 to 27 nm.

The SMF-out size distributions were bimodal.

The majority of the aerosols were distributed in accumulation mode with average median diameter ranging from 105 to 108 nm.



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Results:
Total Surface Area of Aerosols Deposited in Alveolar Region (NSAM)

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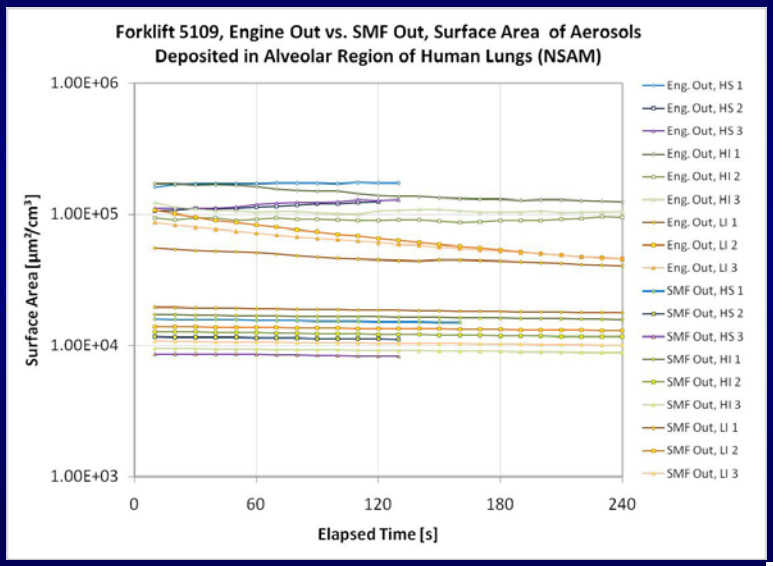
The surface area of aerosols deposited in alveolar region of lungs were measured upstream and downstream of SMF system installed on of the forklift 5109 using NSAM for three series of sequential two-minute (HS) and four-minute (HI&LI) tests.



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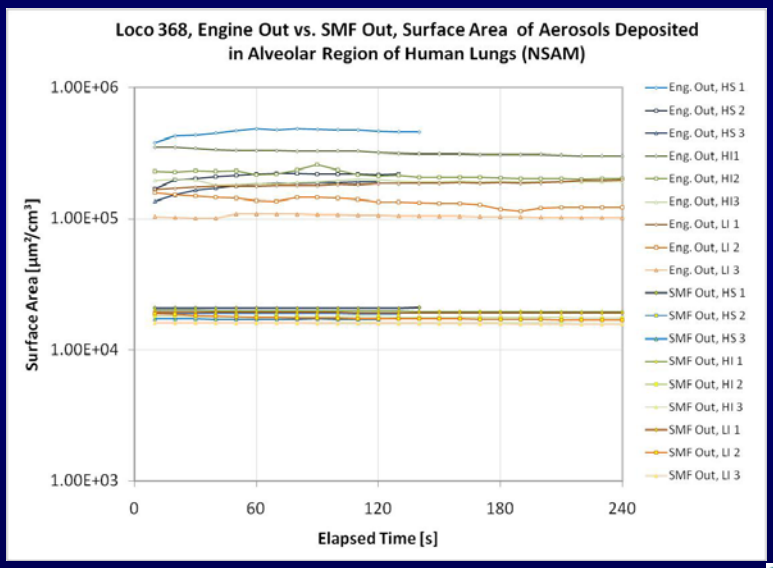
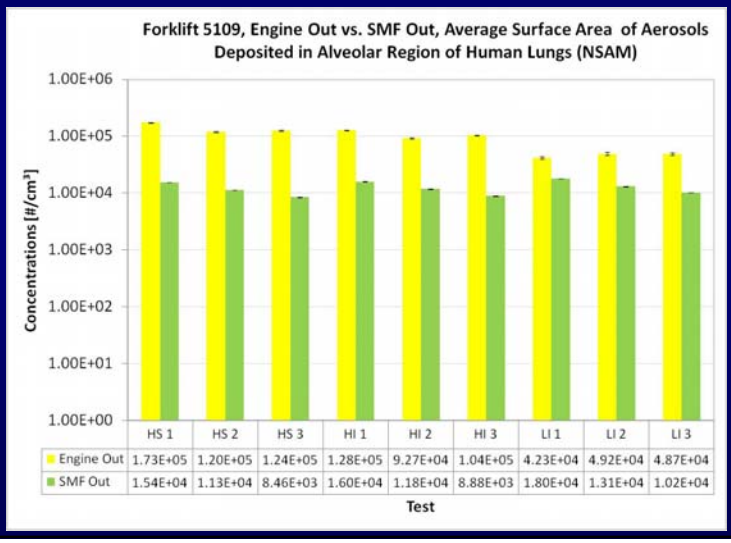
Similarly, the surface area of aerosols in the diluted exhaust of the loco 368 were measured upstream and downstream of SMF system using NSAM for three series of sequential two-minute (HS) and four-minute (HI&LI) tests.



29

The results of NSAM measurements performed during the last minute of each test were used to calculate average surface area (SA) concentrations. The SA concentrations downstream of the SMF system installed on the forklift 5109 were found to be approximately one to two orders of magnitude lower than corresponding SA concentrations upstream of SMF system.



	HS 1	HS 2	HS 3	HI 1	HI 2	HI 3	LI 1	LI 2	LI 3
Engine Out	1.73E+05	1.20E+05	1.24E+05	1.28E+05	9.27E+04	1.04E+05	4.23E+04	4.92E+04	4.87E+04
SMF Out	1.54E+04	1.13E+04	8.46E+03	1.60E+04	1.18E+04	8.88E+03	1.80E+04	1.31E+04	1.02E+04

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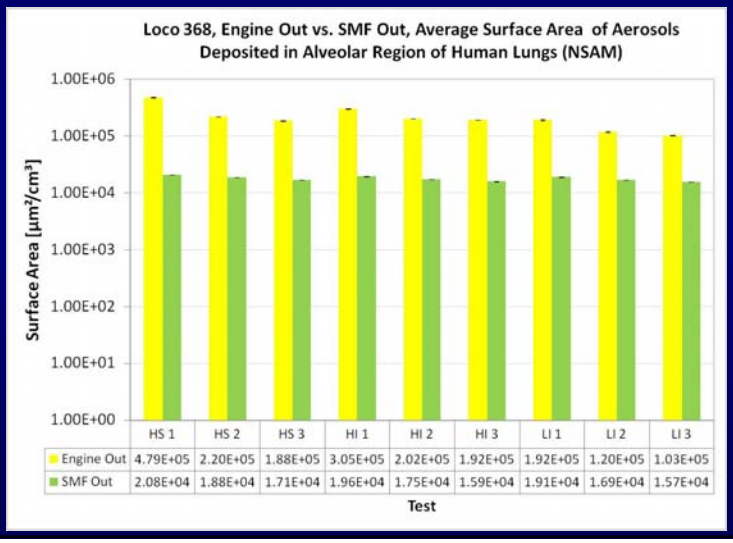
The similarly determined SA concentrations downstream of the SMF system installed on the loco 368 were found to be between one and two orders of magnitude lower than corresponding SA concentrations upstream of SMF system.



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When compared with corresponding surface area concentrations measured upstream of those systems, the surface area concentrations measured after SMF systems were found to be at least 57% lower.

Test	Forklift 5109, Reductions [%]	Loco 368, Reductions [%]
HS 1	91.1	95.7
HS 2	90.5	91.4
HS 3	93.2	90.9
HI 1	87.6	93.6
HI 2	87.3	91.3
HI 3	91.5	91.7
LI 1	57.5	90.1
LI 2	73.3	85.9
LI 3	79.1	84.7

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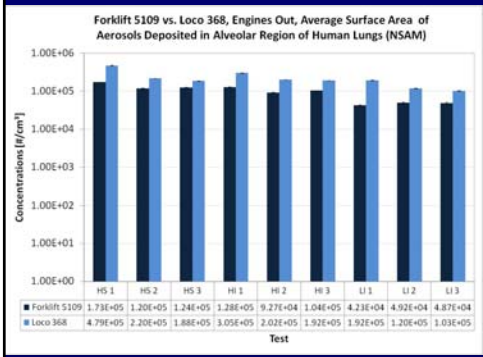
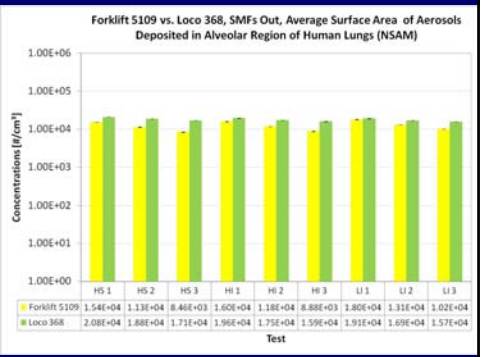
The differences in the efficiency numbers for those two systems can be explained by the fact that the loco 368 engine emitted aerosol with substantially higher SA concentrations than the forklift 5109 engine while the aerosols at the outlet of SMF systems installed on both of those engines had relatively similar SA concentrations.





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Conclusion and Future Activities

- This testing showed that SMF systems are very effective in reducing number and surface area concentrations of aerosols emitted by tested diesel engines.
- The effects on CO and NO emissions are found to be relatively minor. It appears that substantial fraction of NO_2 is consumed in soot oxidation process.
- The additional field testing will be conducted after SMF systems accumulate approximately 1000 hours to establish effects of aging of effectiveness of SMF systems.
- A series of tests will be conducted at NIOSH Diesel Laboratory at Office of Mining Safety and Health Research (OMSHR) to study the effects of DT7 (Satacen® 3) or DT8i (Satacen®) additives on emissions of aerosolized metals and hydrocarbons .

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Thank you for your attention!!!

Acknowledgements go to:

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Douglas O'Connor , Vale Creighton Mine

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