21st ANNUAL MDEC CONFERENCE
Toronto Airport Hilton Hotel, Canada
October 6 – 8, 2015

MDEC DIESEL WORKSHOP
NO_2 and DPM Measurement Techniques

PRESENTED BY

Ron Duke (ECOM)

Jason Morton and Kevin Villeneuve (Draeger)

Brent Rubeli (CanmetMINING)

Brian Davies AM (University of Wollongong)

Erkki Lamminen (Dekati Ltd.)

Scott Norman (TSI Inc.)

COORDINATED BY

David Young and Mahe Gangal (Natural Resources Canada)

OCTOBER 6, 2015

MDEC Diesel Workshop

NO_2 and DPM Measurement Techniques

Hilton Toronto Airport Hilton & Suites
Ontario, Canada

Tuesday, October 6, 2015

Contents

MDEC Diesel Workshop

NO_2 and DPM Measurement Techniques

Hilton Toronto Airport Hilton & Suites
Ontario, Canada

Tuesday, October 6, 2015

07:30 – 08:30	Breakfast and registration
08:30 – 12:00	Welcome – Mahe Gangal, Co-chair MDEC Conference
	Introduction of speakers – David Young, Secretary & Treasurer MDEC
	NO_2 measurement techniques
	Section 1 - (ECOM) Section 2 - (Draeger) Section 3 – (CanmetMINING)
12:00 – 13:00	Lunch
13:00 – 16:30	DPM measurement techniques
	Section 1 - (Brian Davies) Section 2 - (Dekati Ltd.) Section 3 - (TSI Inc.)
	Discussion and Conclusion, JP Ouellette, Co-chair MDEC Conference

MDEC – 2015
Workshop Address List

Richard Banting Workplace Safety North 690 McKeown Avenue North Bay, Ontario P1B 9P1	Bus: (705) 474-7233 Fax: (705) 472-5800 Email: rickbanting@workplacesafetynorth.ca
Tyler Beck Particle Instruments LLC PO Box 270393 Vadnais Heights, MN 55127 USA	Bus: (612) 328-2722 Fax: (651) 407-9050 Email: tyler@particleinstruments.com
Mikael Bergfors Sandvik	Bus: +358456576913 Email: mikael.bergfors@sandvik.com
Boyd Bishop SMM Pogo Mine PO Box 145 Delta Junction, Alaska 99737 USA	Bus: (907) 895-2744 Email: boyd.bishop@smmpogo.com
Darrell Brown Goldcorp Musselwhite Mine PO Box 7500 Thunder Bay, Ontario P7B 6S8	Bus: (807) 928-2200 Fax: (807) 928-2258 Email: darrell.brown@goldcorp.com
Aleksandar Bugarski CDC/NIOSH/OMSHR 626 Cochrans Mill Road Pittsburgh, PA 15236 USA	Bus: (412) 386-5912 Fax: (412) 386-4917 Email: ABugarski@cdc.gov
Kevin Burkholder Cementation Canada Inc. 590 Graham Drive North Bay, Ontario P1B 7S1	Bus: (705) 472-3381 Cell: (705) 475-8378 Email: kevin.burkholder@cementation.com
Louis Chalifoux Hewitt Equipment Limited 5001 Transcanada Highway Pointe-Claire, Quebec H9R 1B8	Bus: (514) 208-1145 Email: pjimenez@hewitt.ca
Jamie Cresswell Ministry of Labour 159 Cedar Street, Suite 302 Sudbury, Ontario P3E 6A5	Bus: (705) 564-7407 Fax: (705) 564-7435 Email: Jamie.cresswell@ontario.ca

Ronald Duke
ECOM America Ltd.
1628 Oakbrook Drive
Gainesville, GA 30507 USA
Bus: (770) 532-3280
Fax: (770) 532-3628
Email: Ronald.duke@ecomusa.com

Aaron Fontana
ADF Diesel
6103 Shawson Drive
Mississauga, Ontario L5T 1E4
Bus: (647) 220-1723
Email: aaron.fontana@hotamil.com

Mahe Gangal
Head, Diesel Emissions
CanmetMINING
1 Haanel Dr., Bldg. #9
Nepean, Ontario K1A 1M1
Bus: (613) 996-6103
Fax: (613) 996-2597
Email: mahe.gangal@canada.ca

Dwaine Gaudette
Goldcorp Musselwhite Mine
PO Box 7500
Thunder Bay, ON P7B 6S8
Bus: (807) 928-2200 x 5140
Fax: (807) 928-2258
Email: dwaine.gaudette@goldcorp.com

Wade Gies
Construction Machinery Industrial, LLC
235 Glacier Avenue
Fairbanks, Alabama 99701 USA
Bus: (907) 460-0087
Email: wgie1@yahoo.com

Arash Habibi
Tronox Corporation
580 Westvaco Road
Green River, Wyoming 82935 USA
Bus: (307) 872-2594
Email: arash.habibi@tronox.com

Brian Hooten
Tronox
PO Box 872
Green River, Wyoming USA 82935
Bus: (307) 872-2477
Email: brian.hooten@tronox.com

Ryan Jaeger
L&M Radiator
1414 East 37th Street
Hibbing, MN USA 55746
Bus: (218) 290-0557
Email: rjaeger@mesabi.com

Harsimran Kalsi
Ministry of Labour
159 Cedar Street, Suite 301
Sudbury, Ontario P3E 6A5
Bus: (705) 564-7177
Fax: (705) 564-7437
Email: Harsim.Kalsi@ontario.ca

Seppo Karhu
Sandvik Mining and Construction
Vahdontie 19
Turku Finland 20101
Bus: +358400775939
Email: seppo.karhu@sandvik.com

Jussi Koivuniemi
Sandvik Mining

Bus: +358505950686
Email: jussi.koivuniemi@sandvik.com

Brian Kutschke
USW Local 6500
66 Brady Street
Sudbury, Ontario P3E 1C8

Bus: (705) 675-3381
Fax: (705) 675-2438
Email: apaquin@uswsudbury.ca

Erkki Lamminen
Dekati Ltd
Tykkitie 1
FI-36240 Kangasala
Finland

Bus: +358 3 357 8100
Mob: + 358 44 076 8880
Email: erkki.lamminen@dekati.fi

Alain Landry
Glencore –Sudbury
6 Edison Rd.
Falconbridge, Ontario P0M 1S0

Bus: (705) 693-2761 x 3693
Email: alain.landry@glencore-ca.com

Marc Lepage
Hewitt Equipment Limited
5001 Autoroute Transcanadienne
Pointe-Claire, Quebec H9R 1B8

Bus: (514) 630-8978
Email: pjimenez@hewitt.ca

Bill Madura
Tronox
PO Box 872
Green River, Wyoming 82935 USA

Bus: (307) 872-2477
Email: william.madura@tronox.com

Greg Mascioli
Kidd Operations
PO Box 2002 Stn. Main
Timmins, Ontario P4N 7K1

Bus: (705) 267-6885
Email: Greg.Mascioli.glencore-ca.com

Michael Mazzuca
T.F. Hudgins, Inc.
24305 Pine Grove Ct
Farmington Hills, Michigan
48335 USA

Bus: (248) 880-1086
Email: mazzucaman@gmail.com

Sean McGinn
MKNIZD Factors Inc.
340 Parkdale Ave., Suite 134
Ottawa, Ontario K1Y 1P2

Bus: (613) 808-3031
Email: mknizd@gmail.com

John McLeod
Potash Corp. Allan Division
Box 301
Allan, SK S0K 0C0

Bus: (306) 979-4412
Email: John.McLeod@potashcorp.com

Jason Morton
Draeger Safety Canada Ltd.
2425 Skymark Ave. Unit #1
Mississauga, Ontario L4W 4Y6
Bus: (416) 540-2535
Email: Jason.morton@draeger.com

Dave Murray
Potash Corp. Allan
Box 301
Allan, SK
Bus: (306) 257-2153
Email: david.murray@potashcorp.com

Scott Norman
TSI
500 Cardigan Road
Shoreview, MN 55126 USA
Bus: (651) 490-2702
Email: scott.norman@tsi.com

J.P. Ouellette
Kubota Canada Ltd.,
5900 14th Avenue
Markham, Ontario L3S 4K4
Bus: (905) 292-7477
Fax: (905) 294-1554
Email: jpouellette@kubota.ca

Brian Pare
SMM Pogo Mine
PO Box 145
Delta Junction Alaska 99737 USA
Bus: (907) 895-2743
Email: brian.pare@smmpogo.com

Gary Robb
AirFlow Catalyst Systems, Inc.
2144 Brighton-Henrietta Townline Rd
Rochester, New York 14623 USA
Bus: (585) 905-1206
Fax: (585) 295-1515
Email: grobb@airflowcatalyst.com

Jan Romo
Mine Mill Local 598/Unifor
2550 Richard Lake Drive
Sudbury, Ontario P3G 0A3
Bus: (705) 673-3661
Fax: (705) 673-1183
Email: natalie.williamson@minemill598.com

Brent Rubeli
CanmetMINING
1 Haanel Dr., Bldg. #9
Nepean, Ontario K1A 1M1
Bus: (613) 996-6285
Fax: (613) 996-2597
Email: brent.rubeli@canada.ca

Wayne Scrivens
Sandvik
72 Turnbull Drive
East Maitland, NSW 2323 Australia
Bus: +61408728563
Email: wayne.scrivens@sandvik.com

Paul Sheremeto
Pattern Discovery Technologies Inc.
554 Parkside Drive
Waterloo, Ontario N2L 5Z4
Bus: (519) 888-1001 x 249
Fax: (519) 884-8600
Email: paul.sheremeto@patterndiscovery.com

Rick Shulist
Ministry of Labour
217 York Street, 5thFloor
London, Ontario N6A 5P9
Bus: (519) 646-3249
Email: rick.shulist@ontario.ca

Branden Sitterud
Mac's Mining Repair
225 West 400 South
Huntington, UT 84528 USA
Bus: (435) 687-2244
Email: branden_mmrs@yahoo.com

Jozef Stachulak
MIRARCO
935 Ramsey Lake Road
Sudbury, Ontario P3E 2C6
Bus: (705) 562-7279
Email: jstachulak@mirarco.org

Glenn Staskus
Ministry of Labour
159 Cedar Street, Suite 302
Sudbury, Ontario P3E 6B5
Bus: (705) 564-4165
Fax: (705) 564-7435
Email: Glelnn.Staskus@ontario.ca

John Stekar
Catalytic Exhaust Products Ltd.
30 Intermodal Drive
Brampton, Ontario L6T 5K1
Bus: (905) 799-9770
Fax: (905) 799-9771
Email: cep89@aol.com

Evelynn Stirling
Cummins Inc.
500 Jackson Street
Columbus, Indiana 47201 USA
Bus: (812) 377-6145
Email: Evelynn.j.stirling@cummins.com

Paul Summers
Miller Technology Inc.
175 Eloy Road
North Bay, Ontario P1B 9T9
Bus: (705) 476-4500
Fax: (705) 476-8811
Email: psummers@millertechnology.com

Karsten Taudte
Cummins Inc.
Peter-Traiser-Strasse 1
Gross Gerau GERMANY 64521
Bus: +491713065136
Email: karsten.taudte@cummins.com

Ben Thompson
Atlas Copco
12950 Quivas Way
Westminster, Colorado 80234 USA
Bus: (720) 485-1007
Email: ben.thompson@us.atlascopco.com

Darcy Thomson
John Deere Power Systems
PO Box 1000
Grimsby, Ontario L3M 4H5
Bus: (905) 945-7350
Email: thomsondarcya@johndeere.com

Adam Tonnos Toromont CAT 25 Mumford Road Sudbury, Ontario P3Y 1K9	Bus: (705) 665-1807 Email: atoonos@toromont.com
Jeanot Tourneur Barminco 390 Stirling Crescent Hazelmere, Western Australia 6055	Bus: +0 41 923 5055 Fax: + 61894161245 Email: jeanot.tourneur@barminco.com.au
Kevin Villeneuve Draeger Safety Canada Ltd., 3121 Just Street Val Caron, Ontario P3N 0A3	Bus: (705) 665-0517 Email: kevin.villeneuve@draeger.com
Juha Virta Sandvik Mining	Bus: +358405962638 Email: juha.virta@sandvik.com
Michael Welsh Ministry of Labour 347 Preston Street, Suite 430 Ottawa, ON K1S 3J4	Bus: (613) 727-2839 Fax: (613) 727-2900 Email: michael.welsh@ontario.ca
Dee Wise Volvo Penta 1300 Volvo Penta Drive Chesapeake, VA 23320 USA	Bus: (757) 284-4232 Email: dee.wise@volvo.com
David A. Young CanmetMINING 1 Haanel Dr., Bldg. #9 Nepean, Ontario K1A 1M1	Bus: (613) 943-9265 Fax: (613) 996-2597 Email: david.young@canada.ca

ecom
Intelligent Analysis

MINING DIESEL
mdec
EMISSIONS COUNCIL

ecom
Intelligent Analysis

Market Leader for Industrial Emissions Analyzers

- Developing portable emissions analyzers is our core competency
- American Headquarters in Georgia, USA - manufacturing in Iserlohn, Germany
- All primary components developed and manufactured in-house **"German Engineering"**
- Tools: - Rugged - Reliable - Accurate - Lightweight
- Quality control and assembly in-house

ecomusa.com

Worldwide References

ecomusa.com

Emissions Formation

- Air consist primarily of Nitrogen (N_2) 78% and Oxygen (O_2) 20.9%
- Fuel is molecular chains of Hydrogen (H_2) and Carbon (C) generically called Hydrocarbons
- Fuel + air + ignition = combustion
- Ideal combustion (stoichiometric combustion) but combustion is never perfect
- As N_2, O_2, C_xH_y and other components are oxidized (burned), different chemical compounds are formed:

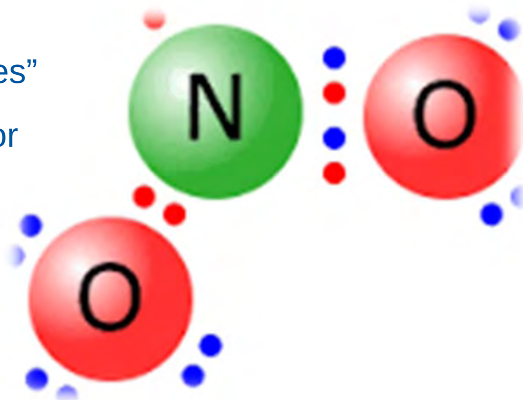
  CO, CO_2, NO, NO_2, (NO_x), SO_2, O_2 & HC

ecomusa.com

ecom
Intelligent Analysis

What is NO_2?

- NO_2 is the abbreviation for “nitrous oxides”
- The value of NO_2 can be an indication for the quality of combustion
- The quality of combustion in turn can be evidence functioning of the engine



ecomusa.com

ecom
Intelligent Analysis

Estimating the NO_2 value of the current NO value

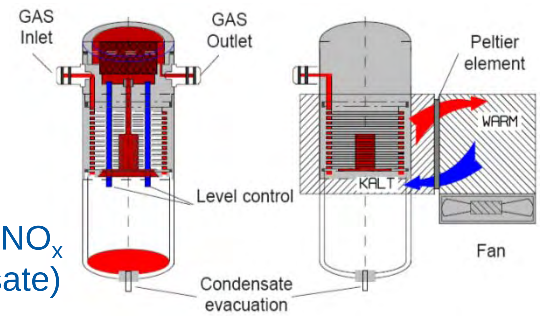
- In exhaust gases, NO_x is primarily NO, but in the atmosphere all NO coverts to NO_2
- If there is no demand for the reading to be exact, the NO_2 value can be estimated using the NO value

- Advantage
  - Does not require a NO_2 sensor
  - Lower maintenance charges
  - Smaller analyzer
- Disadvantages
  - Calculation is based upon empirical data
  - The measurement range and accuracy cannot fully be specified

ecomusa.com

Technology Required For Accurate Analysis

- Sample conditioning
  - Peltier Cooler
  - Particulate filters
  - Smoke filters
  - NO_x/SO_x filters
  - A perfect gas transport (NO_x sleeve to avoid condensate)
- Gas Pump



ecomusa.com

Technology Required For Accurate Analysis

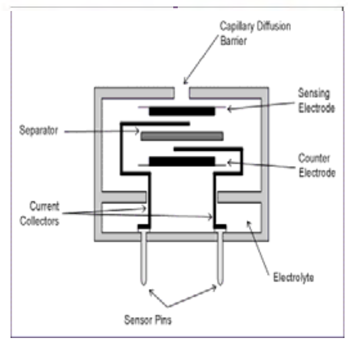
- **Inadequate Sample Conditioning**
  - Gas coolers are generally too small to effectively cool the gas and remove the moisture.
- **Pump Flow Rate Too Low**
  - ECOM uses a 2–3 liter per minute flow. Competitors use 0.5-1.5 liter pump per minute. This means:

    ⇨Slow response time
    ⇨Slow stabilization
    ⇨Limits the use of a longer sample line
    ⇨Allows gas to be in contact with moisture for longer period of time
    ⇨NO_2 drop-out leads to lower NO_x accuracy

ecomusa.com

Technology Required For Accurate Analysis

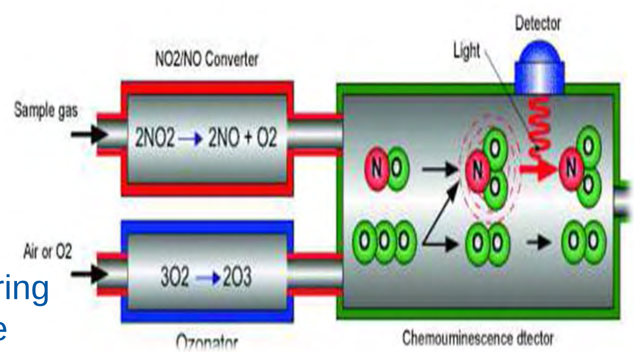
- **Electrochemical sensors**
  - A small capillary allows gas to diffuse into the sensor at controlled rate
  - A chemical reaction occurs (oxidation or reduction)
  - The chemical reaction generates a current
  - This current is directly proportional to the concentration of the gas



ecomusa.com

Technology Required For Accurate Analysis

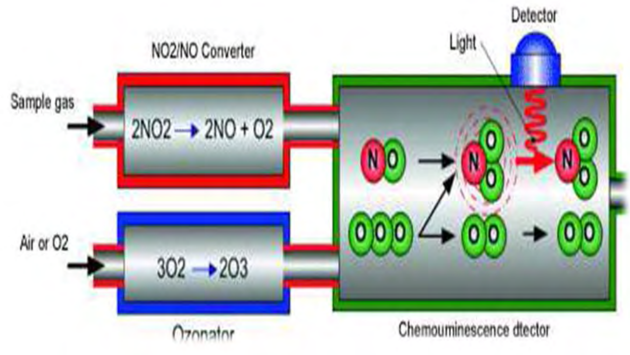
- **CLD (Chemiluminescence) Module**
  - To measure NO_2 the gas has to be reduced with a catalyst to NO
  - The resulting NO gas is mixed with Ozone (O_3) in the cuvette
  - O_3 and NO react to O_2 and NO_2. During this reaction, energy is emitted by the emission of light (luminescence)



ecomusa.com

Technology Required For Accurate Analysis

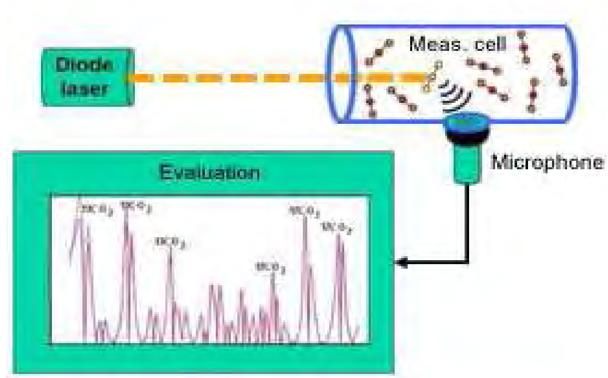
- **Accuracy**
  - ± 2% (f.s.)
- **Advantages**
  - More exact than electrochemical sensors
  - Low maintenance
- **Disadvantages**
  - Higher initial cost
  - Larger structural shape



ecomusa.com

Technology Required For Accurate Analysis

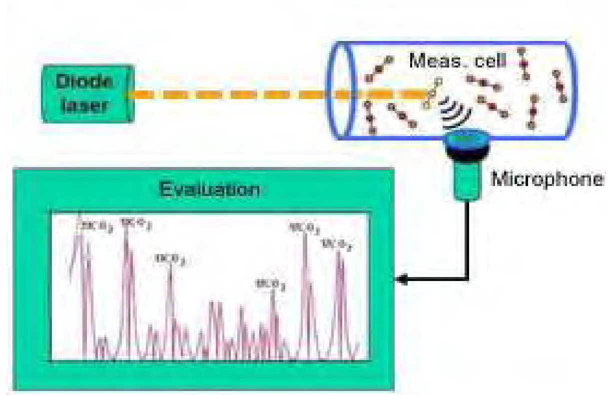
- **PAS Module**
  - PAS is the abbreviation for "Photo-Acoustic Spectroscopy"
  - To generate detectable acoustic waves, the NO_2 gas is targeted by a pulsating infrared laser at a defined wave length
  - The physical reaction of the NO_2 gas emits detectable acoustic waves



ecomusa.com

Technology Required For Accurate Analysis

- **Accuracy**
  - ± 2% (f.s.)
- **Advantages**
  - Most exact method
  - Low maintenance
- **Disadvantages**
  - High cost
  - Larger structural shape



ecomusa.com

Calibration Methods

- With the exception of the O_2 sensor, all sensors are calibrated using the same steps:
  - ⇨ Connect calibration gas to analyzer using one of the following setups.
  - Use either an on-demand regulator or vented flow meter.
  - For a vented flow meter ensure that sensors are not over or under pressurized. Allow the pump to control the analyzer's internal pressure.
  - Adjust the flow to match the pump draw (measure the flow rate of the pump using the on-board flow meter).

ecomusa.com

Basic Emission Testing Procedures

- Set-up analyzer in a stable location, away from sources that may change the temperature of the location significantly.
- Allow analyzer to run for 20 - 30 minutes to reach stable temperature.
- Turn analyzer off and re-power. The analyzer will set accurate zero reference points & temperature compensation curves for the current temperature.
- Insert probe into gas stream and observe the readings on the display.
- Upon completion of sampling, pull sample line and allow analyzer to purge with fresh air for a minimum of 10 minutes or until O_2 readings are above 20.0 % and other readings are below 15 ppm, before powering off.

ecomusa.com

Questions?

Thank you!

Please visit us at www.ecomusa.com

PATTERN DISCOVERY TECHNOLOGIES INC

wsn

Dräger

MDEC Diesel Workshop

NO_2 Measurement Techniques

Dräger. Technology for Life®

Did you know, that …

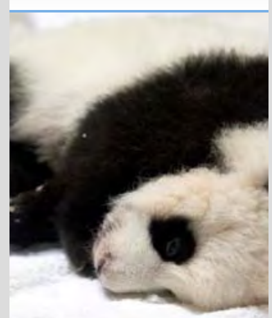
Dräger

… a Dräger-breathing apparatus was used by **Edmund Hillary und Tenzing Norgay** during their first ascent of Mount Everest?

… the in air in the **Bundestag in Berlin** is monitored by Dräger gas monitoring devices?

… the Dräger closed-circuit breathing apparatus PSS BG4 saved the life of many people during **9/11 in New York?**

… a Dräger-incubator in Madrid Zoo saved the lives of **two orphaned Panda-Babys?**



MDEC Diesel Workshop | Jason Morton

Dräger Profile
The company in figures

Employees	13,737 (2014)
Net sales	EUR 2,434 million (2014)
Chief Executive Officer	Stefan Dräger (family-run)
Form of business organization	AG & Co. KGaA
Headquarters	Lübeck
Production sites	Germany, Brazil, China, Czech Republic, South Africa, Sweden, United Kingdom, USA, Canada
Sales and service branches	in more than 50 countries

24	140	5,000	6,000
new products each year*	**patents** registered each year*	**respiratory protective devices** produced **each month***	**local sales and service employees***

* Figures from fiscal year 2014

MDEC Diesel Workshop | Jason Morton

Markets
Our customers

Hospital

Fire services

Oil & gas

Mining

Chemical industry

Other markets

MDEC Diesel Workshop | Jason Morton

Dräger

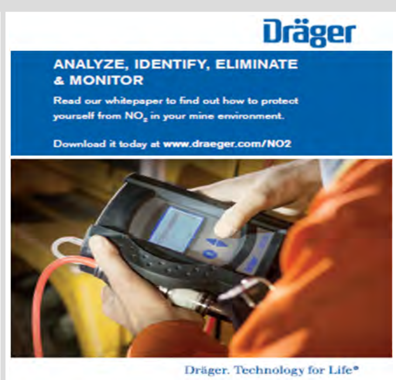
Technology for Life

NO_2 Campaign

Dräger

Mine Safety in Canada and the Legislative Trends Toward Lower NO_2 Limits

- Visit: www.draeger.com/NO2



NO_2 Measurement Techniques

Analyze and continuously monitor the environment

Typical scenarios that require NO_2 detection equipment:

- Clearance after blasting
- Workers in close proximity to diesel engines
- Ventilation checks
- Areas with less ventilation
- Mucking or crushing operations

» Portable and stationary gas detectors

NO_2 Measurement Techniques

Portable gas detection:

- X-am 5000 or X-am 5600 with XXS NO_2 LC sensor:
  - Measuring range: 0–50 ppm
  - Detection limit: 0.04 ppm
  - Resolution: 0.02 ppm
  - Response time T_{90}: 15 s

Outstanding features:

- Very low cross sensitivity to H_2S and SO_2 (much better than any competitor)
- Very low cross sensitivity to NO and CO
- Low humidity sensitivity

NO_2 Measurement Techniques

Stationary gas detection

PointGard II, Polytron 5100, Polytron 7000, and Polytron 8000 with NO_2 LC sensor:

- Measuring range: 0–20 ppm
- Detection limit: 0.05 ppm
- Response time T_{90}: 20 s

» Polytron 5100 and 8000 are explosion proof.

MDEC Diesel Workshop | Jason Morton

NO_2 Measurement Techniques

Identify and eliminate sources

NO_2 cannot be eliminated completely, so steps must be taken to reduce the concentration released:

- Identify equipment that requires service

» Diesel Emission Analyzer

MDEC Diesel Workshop | Jason Morton

NO_2 Measurement Techniques

Diesel Emissions Analyzer

Dräger EM200-E

Designed for performing measure-ments of undiluted diesel engine exhaust gases.

Provides measurement values for CO, NO, NO_2, and NO_x.

» Built-in pressure sensor ensures that measurements performed below or above ground are fully compensated.

MDEC Diesel Workshop | Jason Morton

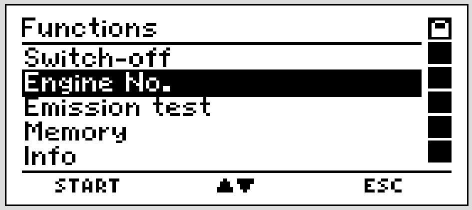
NO_2 Measurement Techniques

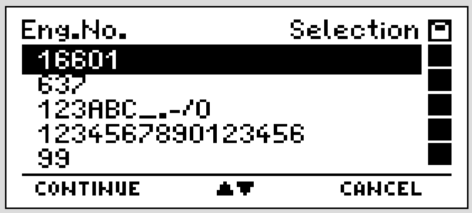
Dräger EM200-E

MDEC Diesel Workshop | Jason Morton

NO_2 Measurement Techniques
Dräger EM200-E

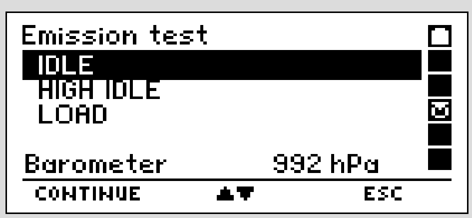
Dräger

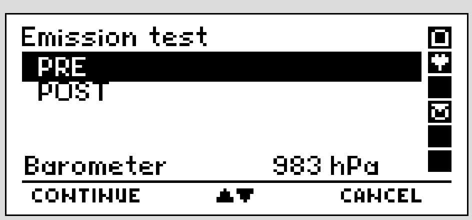




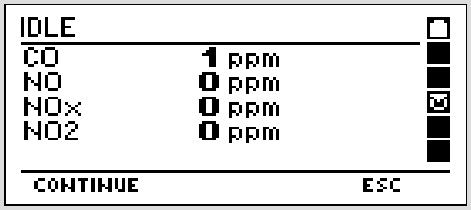
NO_2 Measurement Techniques
Dräger EM200-E

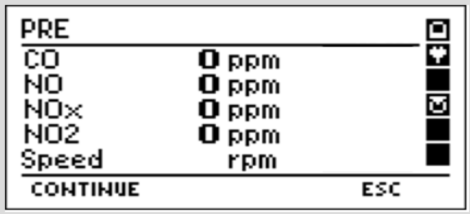
Dräger



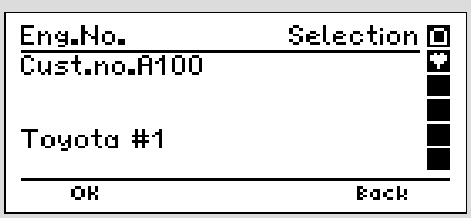


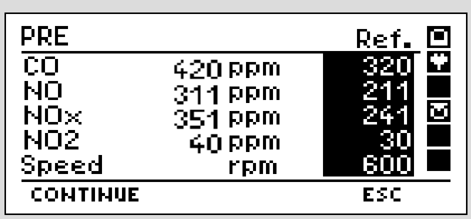
NO_2 Measurement Techniques
Dräger EM200-E





NO_2 Measurement Techniques
Dräger EM200-E





MDEC Diesel Workshop | Jason Morton

NO_2 Measurement Techniques

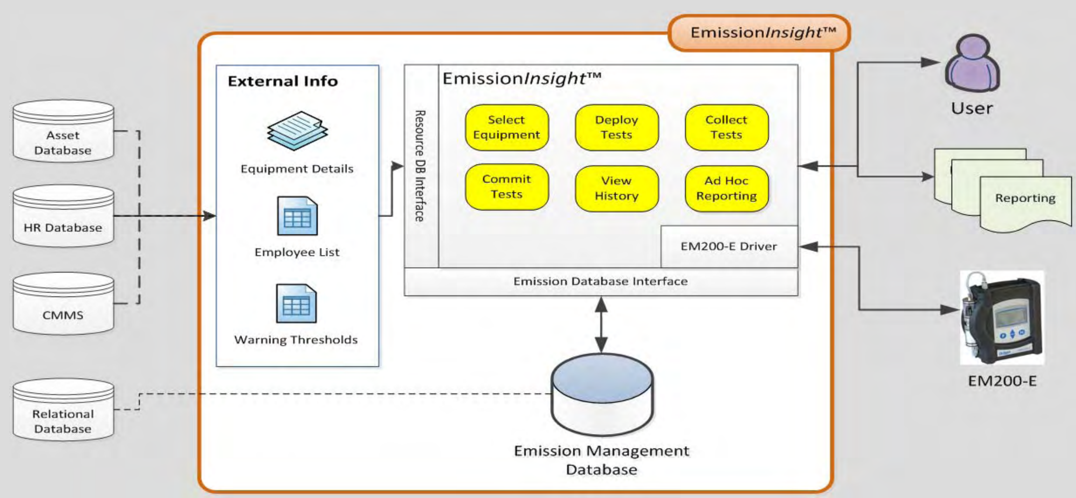
Dräger

Dräger EM-200E features:

- Internal absolute pressure sensor for -4000m to +4000m
- Internal components encased in EPP-foam
- CO Sensor over-range protection
- 8 hour battery life with smart charging circuit
- Magnetic back-plate
- Annual service requirement with pre-warning

NO_2 Measurement Techniques
EmissionInsight™

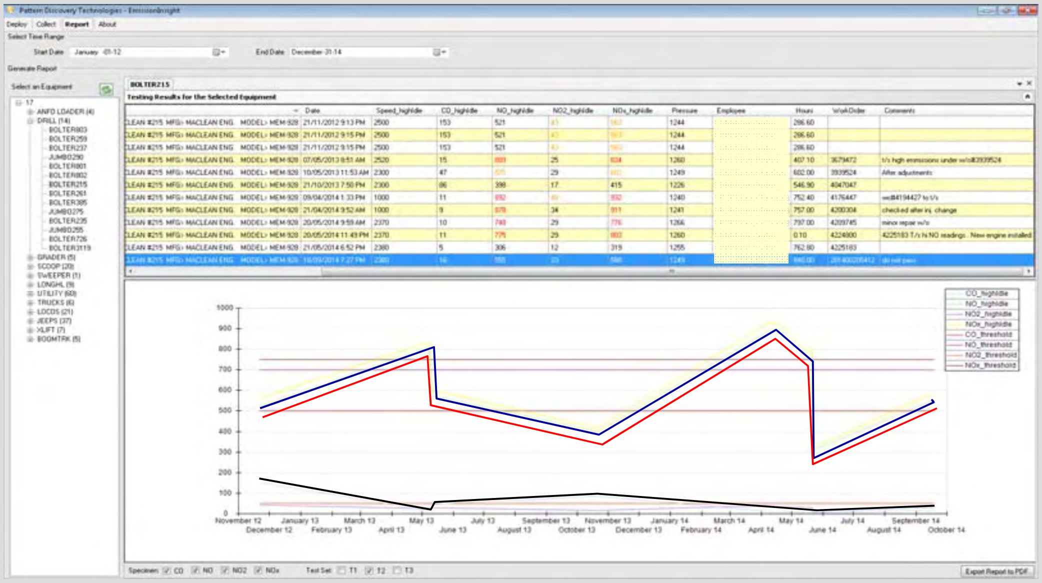
Dräger



PATTERN DISCOVERY TECHNOLOGIES INC

NO_2 Measurement Techniques
EmissionInsight™

Dräger



PATTERN DISCOVERY TECHNOLOGIES INC

NO_2 Measurement Techniques
EmissionInsight™

Dräger

Speed_highIdle	CO_highIdle	NO_highIdle	NO2_highIdle	NOx_highIdle	Pressure	Employee	Hours	WorkOrder	Comments
2500	153	521	43	563	1244	[illegible]	286.60		
2500	153	521	43	563	1244	[illegible]	286.60		
2500	153	521	43	563	1244	[illegible]	286.60		
2520	15	809	25	834	1260	[illegible]	407.10	3679472	t/s high emmissions under w/o#3939524
2300	47	575	29	603	1249	[illegible]	602.00	3939524	After adjustments
2300	86	398	17	415	1226	[illegible]	546.90	4047047	
1000	11	892	40	932	1240	[illegible]	752.40	4176447	wo#4194427 to t/s
1000	9	878	34	911	1241	[illegible]	757.00	4200304	checked after inj. change
2370	10	748	29	776	1266	[illegible]	797.00	4209745	minor repair w/o
2370	11	775	29	803	1260	[illegible]	0.10	4224800	4225183 T/s hi NO readings . New engine installed
2380	5	306	12	319	1255	[illegible]	762.80	4225183	
2380	16	555	33	588	1249	[illegible]	840.00	201400205412	do not pass

PATTERN DISCOVERY TECHNOLOGIES INC

NO_2 Measurement Techniques
Challenges

Dräger

2. Each individual piece of equipment must be tested under consistent conditions so that results from different tests can be compared.

3. Testing must be carried out, as far as is practical, on equipment under full load. O. Reg. 296/11, s. 14 (2).

(2) The employer shall provide the results of every test conducted under subsection (1) to the joint health and safety committee or the health and safety representative, if any, for the workplace. O. Reg. 779/94, s. 7.

(3) The employer shall record the results of every test conducted under paragraphs 2 and 3 of subsection (1) and shall maintain the record. O. Reg. 779/94, s. 7; O. Reg. 296/11, s. 14 (3).

- ❑ Consistent testing procedure
- ❑ State of operation for test – rarely measured under load
- ❑ Safe working conditions for mechanics
- ❑ Time out of production for conducting tests
- ❑ Number of mechanics tied up for test – wrench time

MDEC Diesel Workshop | Jason Morton

PATTERN DISCOVERY TECHNOLOGIES INC

NO_2 Measurement Techniques
SenzLogic

Dräger

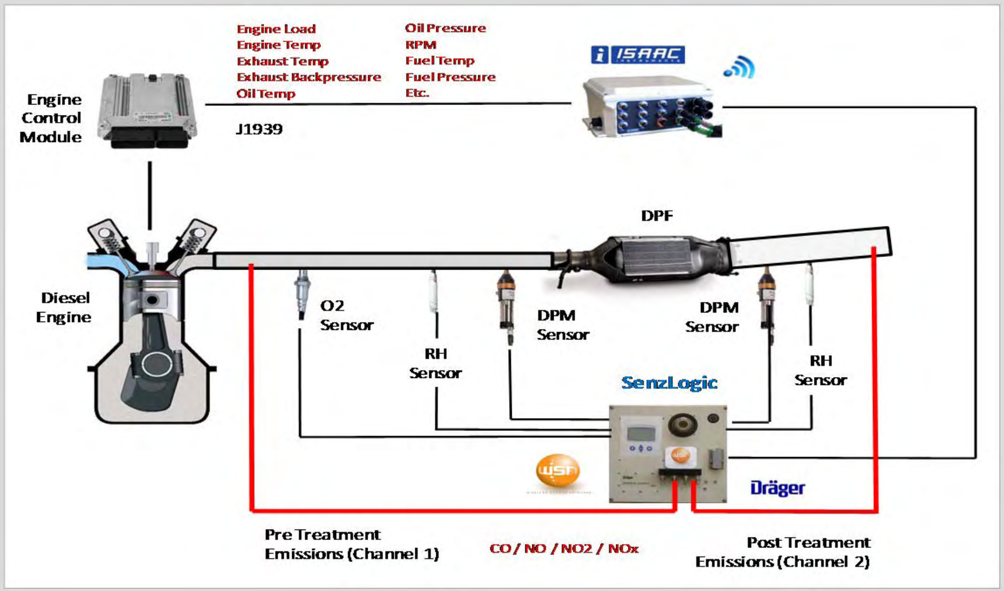
wsn

WIRELESS SENSOR NETWORKS

MDEC Diesel Workshop | Jason Morton

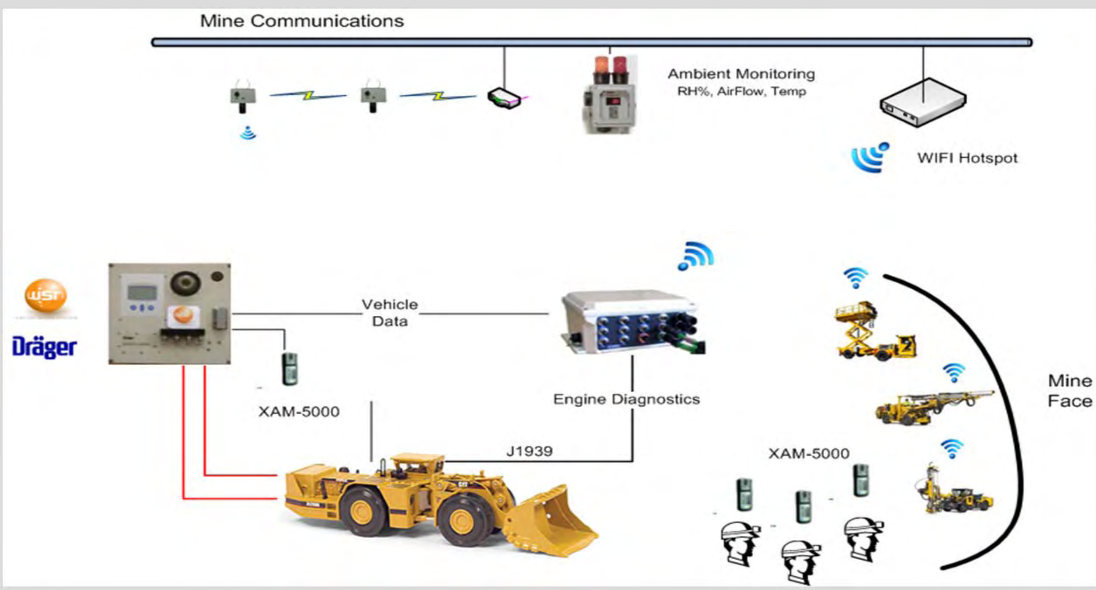
PATTERN DISCOVERY TECHNOLOGIES INC

NO_2 Measurement Techniques
SenzLogic, Extensible Platform



MDEC Diesel Workshop | Jason Morton

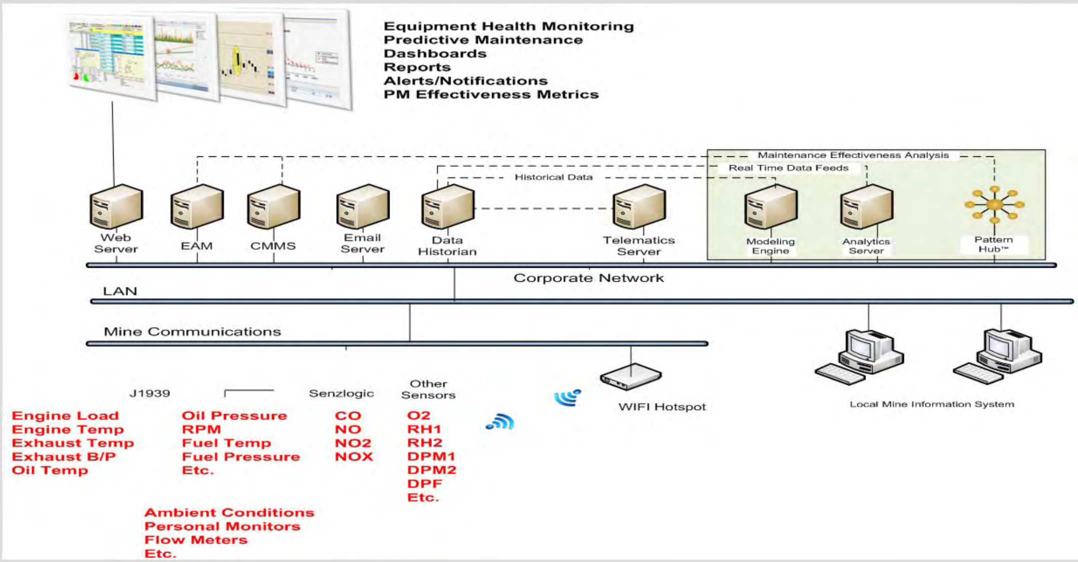
NO_2 Measurement Techniques
Communications for remote monitoring



MDEC Diesel Workshop | Jason Morton

NO_2 Measurement Techniques
AssetInsight™ - Analytics and Reporting

Dräger



MDEC Diesel Workshop | Jason Morton

PATTERN DISCOVERY TECHNOLOGIES INC

NO_2 Measurement Techniques
AssetInsight™ - Pilot, Development Vision, Impacts

Dräger

Maintenance

- ✓ Centre of Excellence
- ✓ Incorporate Modern Delivery Mechanisms
- ✓ Develop Repair Best Practices
- ✓ Develop Troubleshooting Guidelines
- ✓ Evaluate Maintenance Effectiveness
- ✓ Develop Sets of KPI's

Ventilation

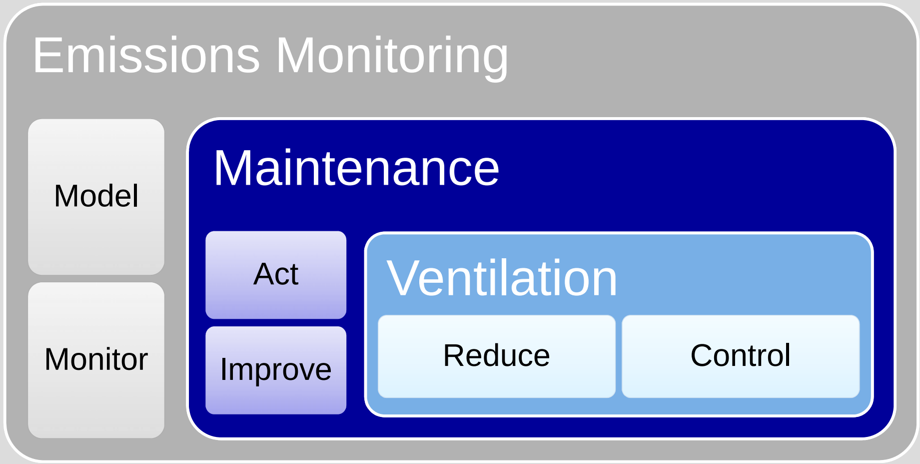
- ✓ Ventilation on Demand
- ✓ Provide Evidence to Challenge Ventilation Rate (100cfm/bhp)
- ✓ Monitor DPF Efficiency
- ✓ Accurate Ambient Conditions
- ✓ Monitor Equipment Output

Model "States" of Operation and Report Emissions	•Correlate emissions measurements to engine operating parameters to model states of operation. •Report on emissions. Tag and notify regarding threshold violations •Compliance to Occupational Health and Safety Act
Onboard Emissions Monitoring	•Measurement of Pre and Post DPF treatment – true measures of emissions •Measurement interval refinement based on duty cycle and vehicle type
Engine and Operator Diagnostics	•Real time or near real time monitoring through existing communications infrastructure •Shift by shift download dumps •Reporting and condition notifications

PATTERN DISCOVERY TECHNOLOGIES INC

NO_2 Measurement Techniques

Emissions Monitoring – Impact on Maintenance and Ventilation



Emissions Monitoring is the foundation for understanding equipment health, improving maintenance programs through timely intervention and controlling ventilation to maximize production and control energy costs

PATTERN DISCOVERY TECHNOLOGIES INC

Dräger

Thank you for your attention.

Jason Morton
Product and Application Support Specialist
Draeger Safety Canada Ltd.
905-212-6576
Jason.Morton@draeger.com

Kevin Villeneuve
Regional Sales Manager – Northern Ontario
Draeger Safety Canada Ltd.
705-665-0517
Kevin.Villeneuve@draeger.com

Paul Sheremeto
President & CEO
Pattern Discovery Technologies Inc.
519-888-1001 ext 249 Paul.Sheremeto@patterndiscovery.com

Brian Fleury
President & CEO
Wireless Sensor Networks
705-662-8051
bfleury@wsninc.ca

Dräger. Technology for Life®

On The Road To Clear Skies ™

Sensors, Inc.
Portable On-Vehicle Emission Systems
SEMTECH-ds/ppmd

Instrumented hybrid loader-shuttle.

Background

- EPA embarks on a program to measure all regulated emissions *in-use* in the late 1990's.
- Sensors, Inc. introduces semtech in 2002, capable of gaseous measurements.
- Sensors, Inc. delivers semtech efm2, capable of extremely precise and accurate flow measurements, in 2004.

Background

- Sensors, Inc. introduces semtech ppmd, for the measurement of particulate mass.
- First demonstration of complete system April, 2006 on cross country trip from Ann Arbor to San Diego and back.

The SEMTECH In-Use Gaseous Emissions Systems

- Development initiated 2000.
- SEMTECH gaseous systems commercially available February, 2002.
- Procured EPA Patent enabling mass emission calculation using exhaust flow meters 2002.
- Established JDA with Ford Motor Company 2004.
- Awarded multiple contracts from USEPA; supplied 18 systems in 2003-6
- Fully compliant with CFR 40, Part 1065, Subpart J for Portable Emissions Measurement Systems (PEMS)

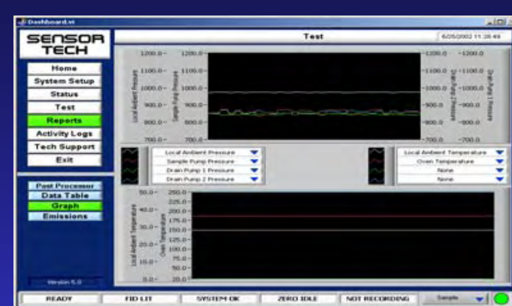
SEMTECH-Ds

ANALYZER FEATURES

- “Lab-in-a-Box” – Laboratory grade analysis capability
- Capable of measurements on both gasoline and diesel engines
- Heated FID and Sample System for THC
- NDUV NO and NO_2 (simultaneous)
- NDIR CO and CO_2
- External weather probe for RH, Temp
- Vehicle Interface (optional)
- Global Positioning System (optional)
- Wireless Communications
- Multiple I/O

New sensortech-pc v10.01 Software Features

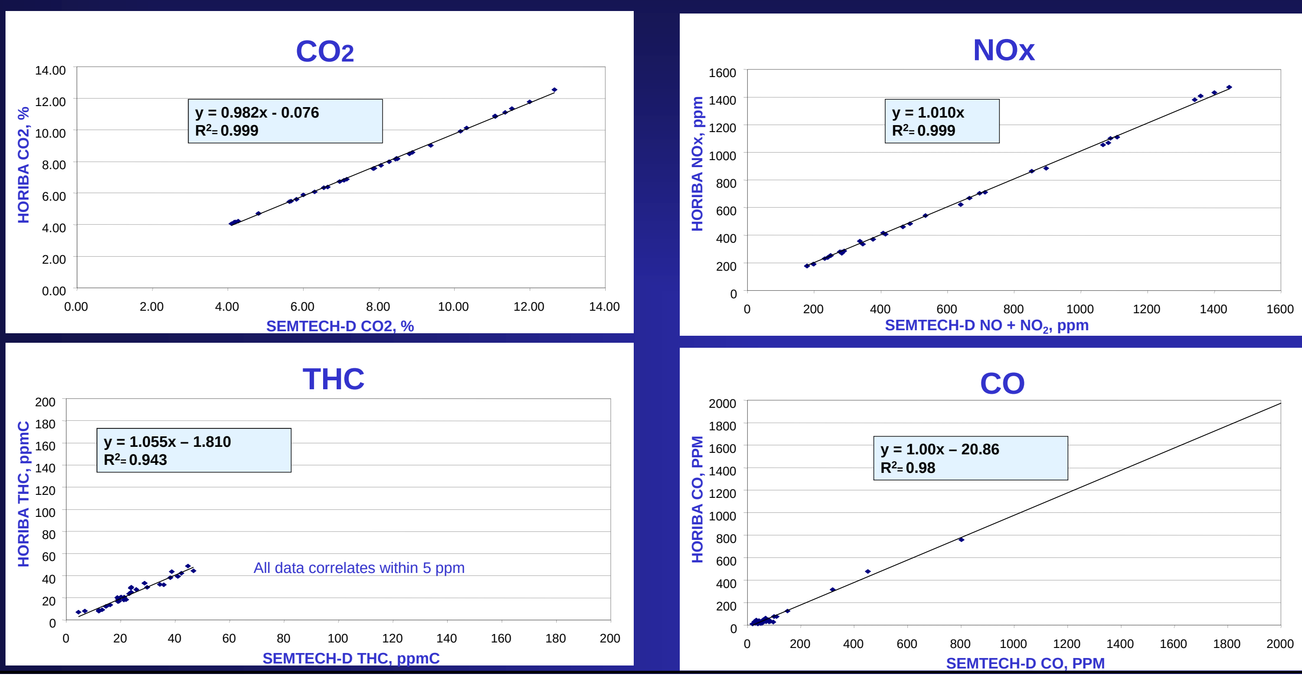
- Session Mgr includes calibration, audit, and test data in same file
- R-T mass and NTE zone display
- Patented ability to calculate brake-specific emissions using VI data
- Raw measurement data recording
- Post-Processor allows “what-if” analysis
- Raw files can contain multiple tests with multiple segments per test
- Recorded files can drive GPS s/w to playback route traveled
- Once set up, SEMTECH runs without a tethered PC



Correlation of SEMTECH-D to Standard Certification Emissions Bench

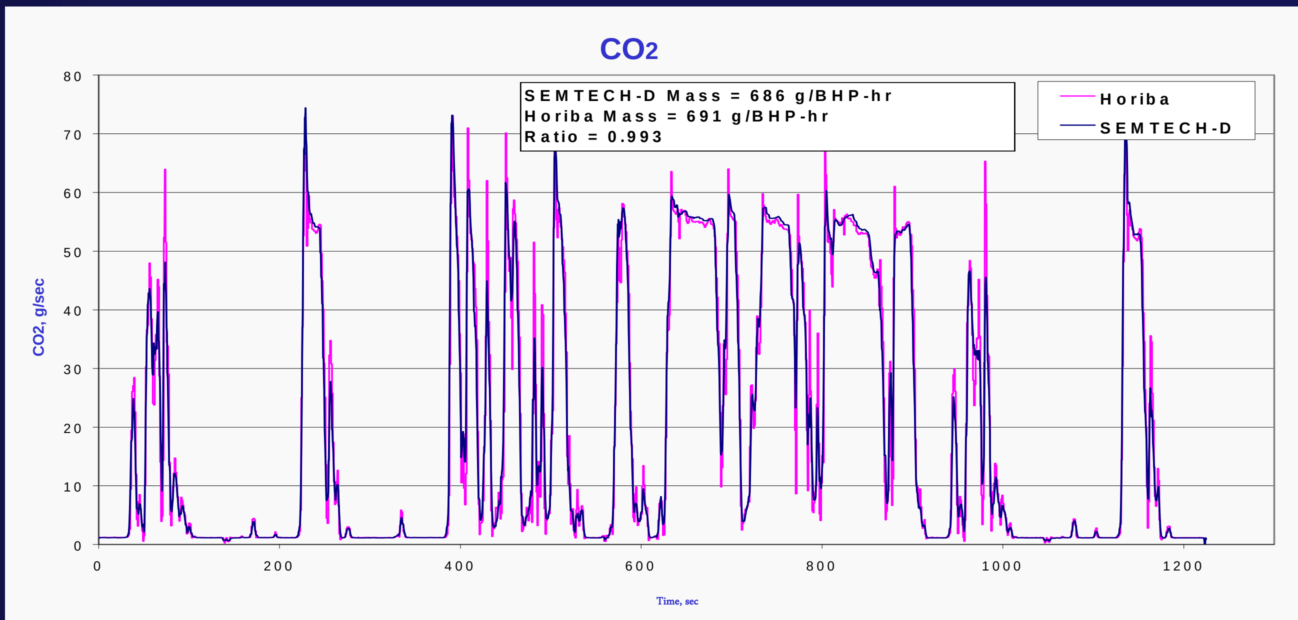
SEMTECH-D Correlation to Horiba Mexa 7100

34 Steady State Tests at International



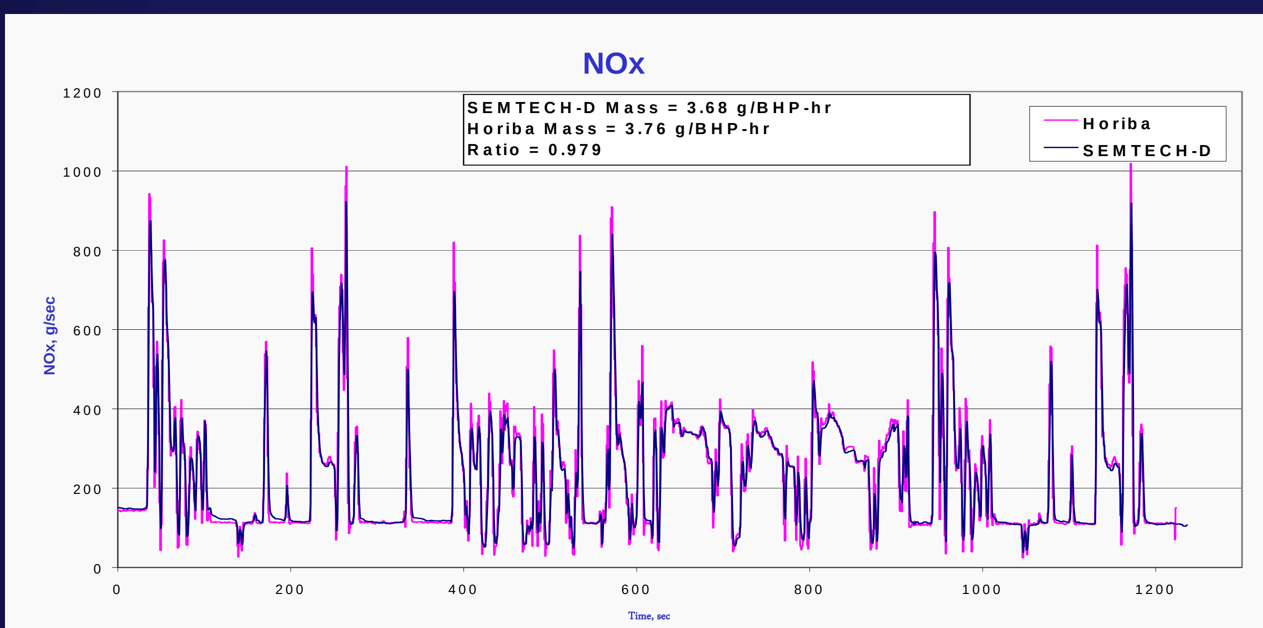
SEMTECH-D Correlation to Horiba Mexa 7100

Calculated Mass Emissions on Transient FTP Cycles at Caterpillar



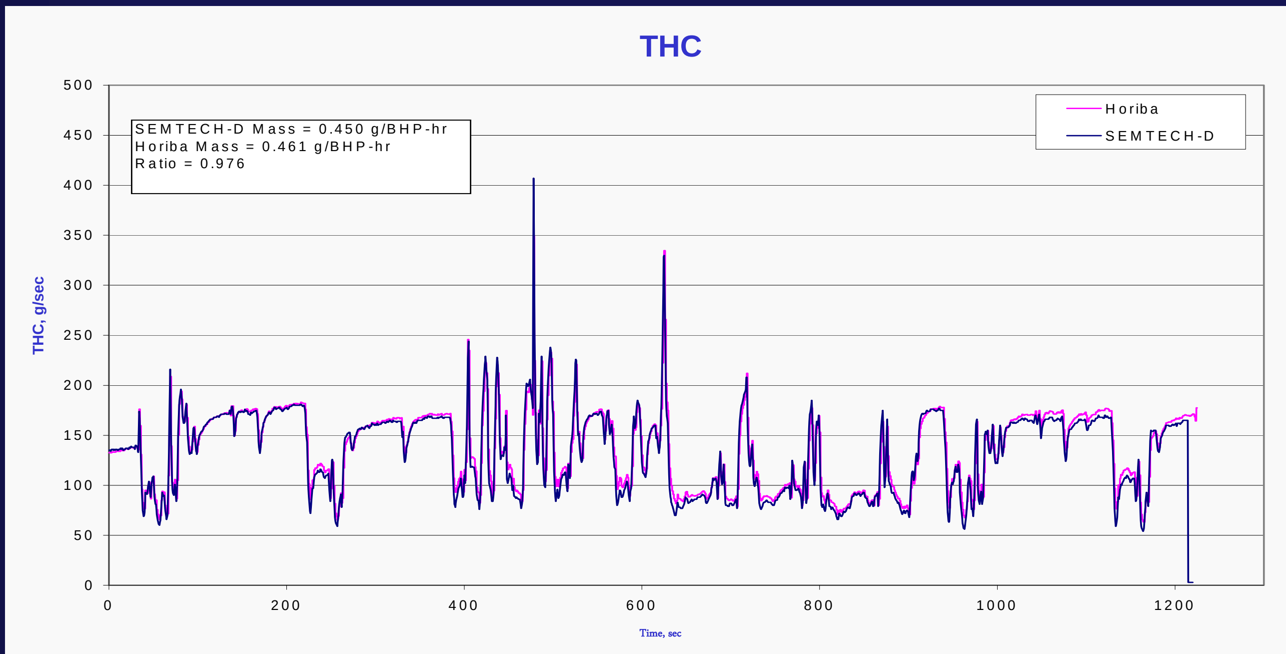
SEMTECH-D Correlation to Horiba Mexa 7100

Calculated Mass Emissions on Transient FTP Cycles at Caterpillar



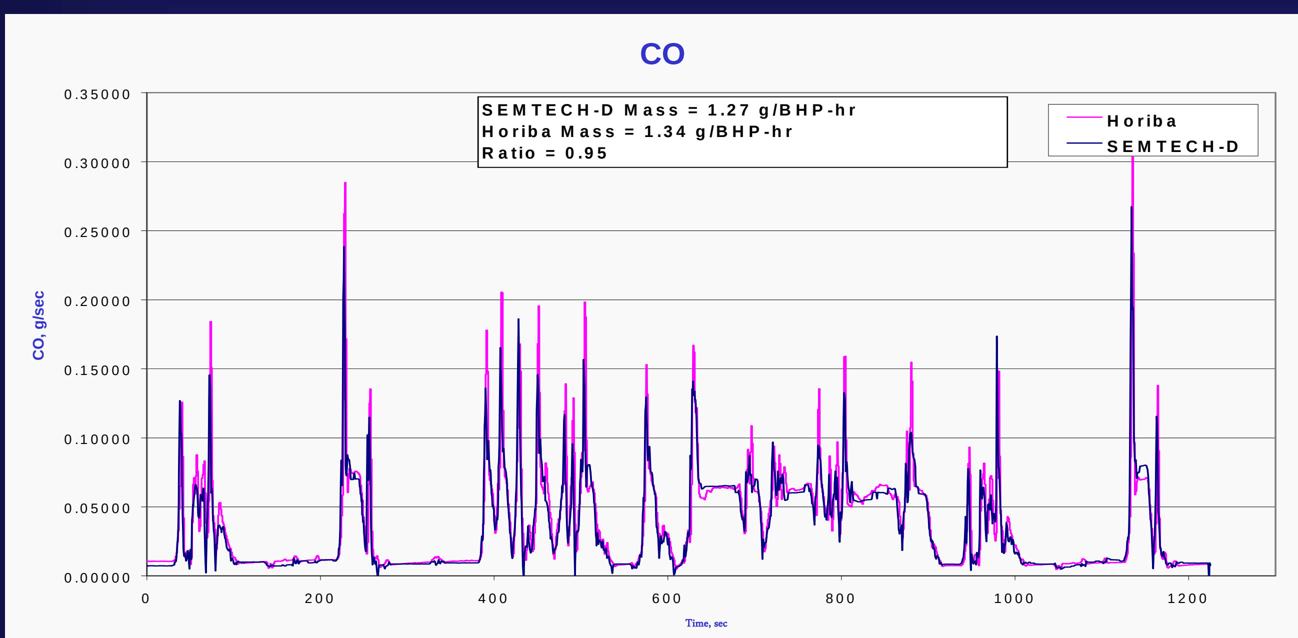
SEMTECH-D Correlation to Horiba Mexa 7100

Calculated Mass Emissions on Transient FTP Cycles at Caterpillar



SEMTECH-D Correlation to Horiba Mexa 7100

Calculated Mass Emissions on Transient FTP Cycles at Caterpillar



Semtech-efm2

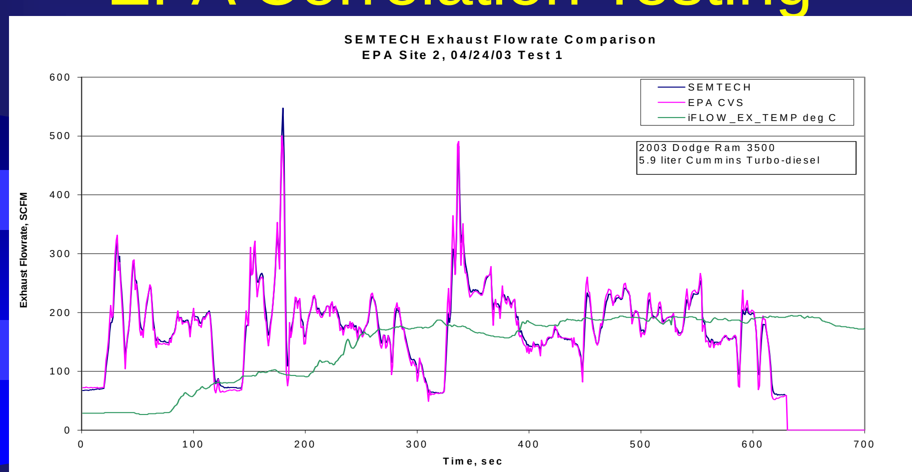
Exhaust Flow Meter

- Pressure differential technology compensated for:
  - Exhaust temperature
  - Exhaust composition
  - Humidity
  - Thermal expansion
- Meets all specifications of ISO 16183 and CFR40 Part 1065, including overall accuracy < 2.5%; linearity < 1%
- Multiple sizes accommodate various applications: 2", 2.5", 3", 4", 5"
- Automatic Zero and Back Purge
- Typical back pressure < 10" H_2O at 200˚C
- Wide dynamic range (e.g. 10 – 1000kg/hr for 3")
- CAN, RS232, DAC interfaces

On The Road To Clear Skies ™

Semtech efm2

3.0" Performance EPA Correlation Testing



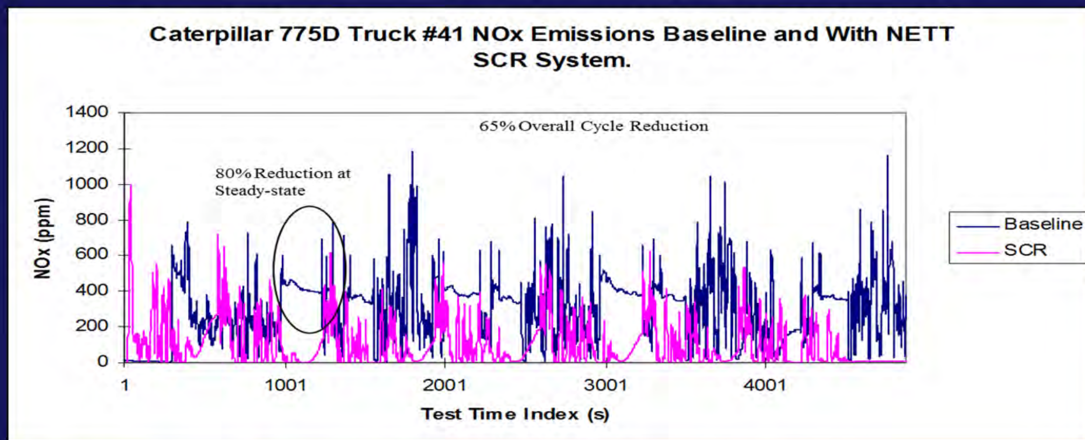
Surface Applications

- Buses/trucks/Commercial vehicles
- Agricultural/Construction/Marine
- Passenger cars light trucks
- Small engines / recreational vehicles

U/G Mining Applications

- Compass Minerals Sifto Salt
  - Biodiesel / SCR retrofit
- Diesel/electric Hybrid research
- Aftertreatment verification

SCR Realtime Emissions



- In-use emissions monitoring over actual production service.

On The Road To Clear Skies ™

Aftertreatment Verification

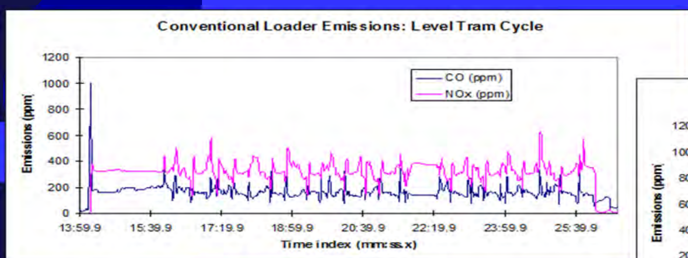
- DOC/DPF/SCR
- NO/NO2
- DPM mass

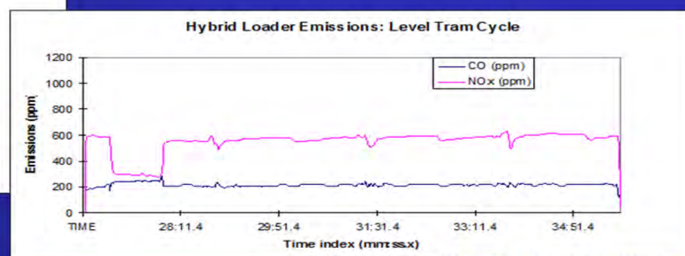
On The Road To Clear Skies ™

Hybrid Research

Instrumented hybrid loader-shuttle.

- Duty cycle validation
- Fuel consumption
- CO_2 emission

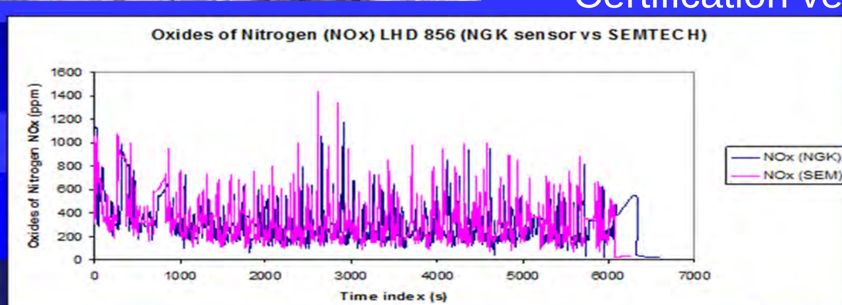




On The Road To Clear Skies ™

Ventilation on Demand

- On-board sensor technology development.
- Real time data transmission.
- Certification vent



Other Applications for SEMTECH Systems

- Research and development tool for field applications.
- In-use verification for mining diesel emissions standards.
- Emissions-based ventilation rate control research.
- Support of CanmetMINING internal and external projects including contract R&D.

www.sensors-inc.com

Raw Exhaust Monitoring in Australia – The Highlights & Pitfalls

Dr Brian Davies AM

MDEC Conference Workshop
October 6, 2015

Topics to be covered

- Overview of raw exhaust monitoring in Australia
- Department of Primary Industries (DPI) project
- Calibration of instrumentation
- Compliance with statutory requirements

Overview of raw exhaust monitoring in Australia

- Pre 2000
  - Bosch smoke meter
- 2000 – 2004
  - R & P 5100
  - DPI project
- 2004 – 2012
  - Introduction of LLS devices
  - Confusion & uncertainty
- 2012-2014
  - Davies (2013), Mason (2014) & Hines, Kon, Bartley & Davies (2014)
- 2015
  - Hines, & Davies (2015)

Pre-2000

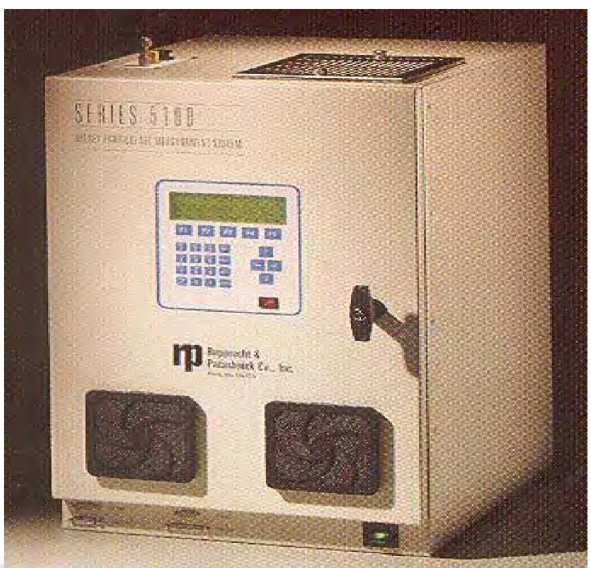
Bosch Smoke Meter

Source: HSE

2000 – 2004: R & P 5100 EC Analyser

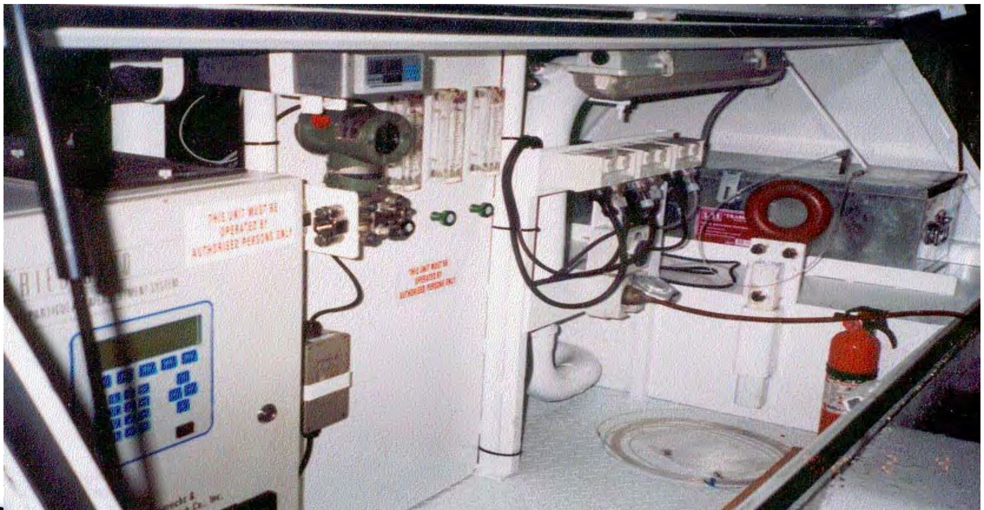
- Laboratory grade instrument capable of measuring OC/EC/TC
- Fitted to a purpose built trailer with full exhaust sampling system
- Part of BHP Billiton Tower Colliery Research Project
- R & P taken over by Fisher Scientific & instrument deleted from product line

R & P Series 5100 Analyser



Source: B Davies

R & P Series 5100 Analyser



Source: B Davies

Raw Exhaust Testing

Source: B Davies

DPI Health & Safety Trust Project

- Aim was to identify & evaluate hand held surrogate devices to measure DP in raw exhaust
- Develop a test procedure suitable for all engines used in industry (including turbocharged engines)
- Aim was to keep cost below $10,000 if possible

Project Timeline

- Project commenced 11 July 2002 under direction of Clive Ellis from NSW DMR
- International review of available instruments
- Dynamometer trials at Londonderry Test Centre using a dilution tunnel (April 2003)
  - Cat 3306
  - KIA
  - Cat 3126

Slide 77

J2 DMR or DPI - Slide 2 talks about DPI
Jen, 9/14/2015

Project Timeline

Selection of Instruments for Field tests
- Dust Trak
- Data Ram
- NIOSH device

Preliminary field trials (Elouera Colliery)

Field Trials (June/July 2004)
- 5 NSW Mines
- 21 different machines

Comparison Methods

- R & P 5100 Diesel Particulate Analyser (Both dynamometer & field trials)
- Gravimetric
- TEOM
- Bosch smoke meter
- NIOSH Method 5040

Load Procedures Evaluated

- Load only test (MDG 29)
- Transient and load test
- Transient test
  - Warm up engine
  - Place in top gear and idle for 30 seconds
  - Full throttle and hold for 20 second
  - No throttle and allow to decay to idle (30 seconds)
  - Disengage gear

  - (Note: MDG 29 now 20sec/20sec/20sec)

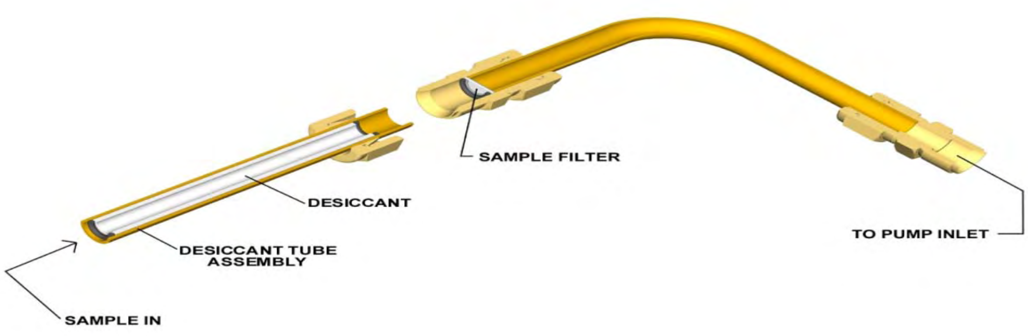
Field Trials-Dust Trak & Data Ram

Source: B Davies

NIOSH Instrument

Source: B Davies

Prototype NIOSH Device



Field Trials-NIOSH Device

Source: B Davies

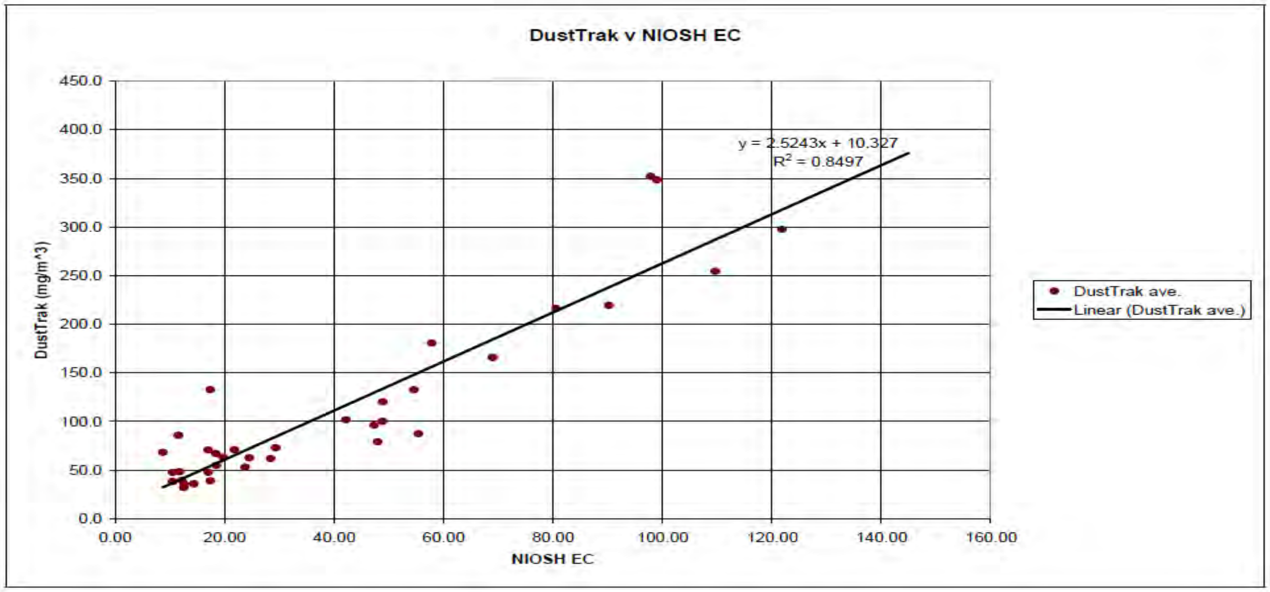
J3

DPI Project – Outcomes

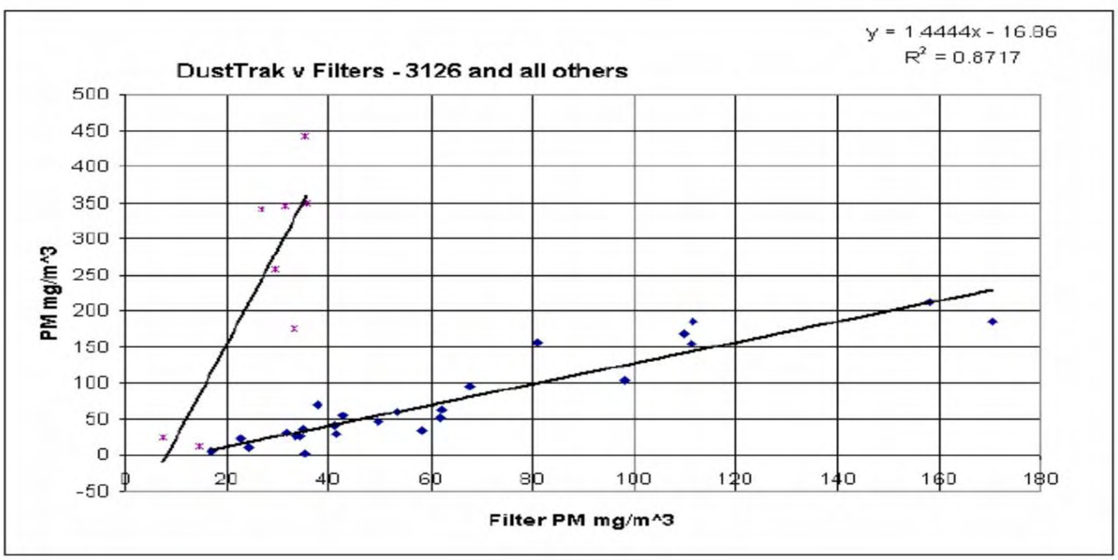
- Possible to measure raw exhaust DPM
- Calibration of instrumentation requires investigation
- Repeatability of results an issue

Slide 86

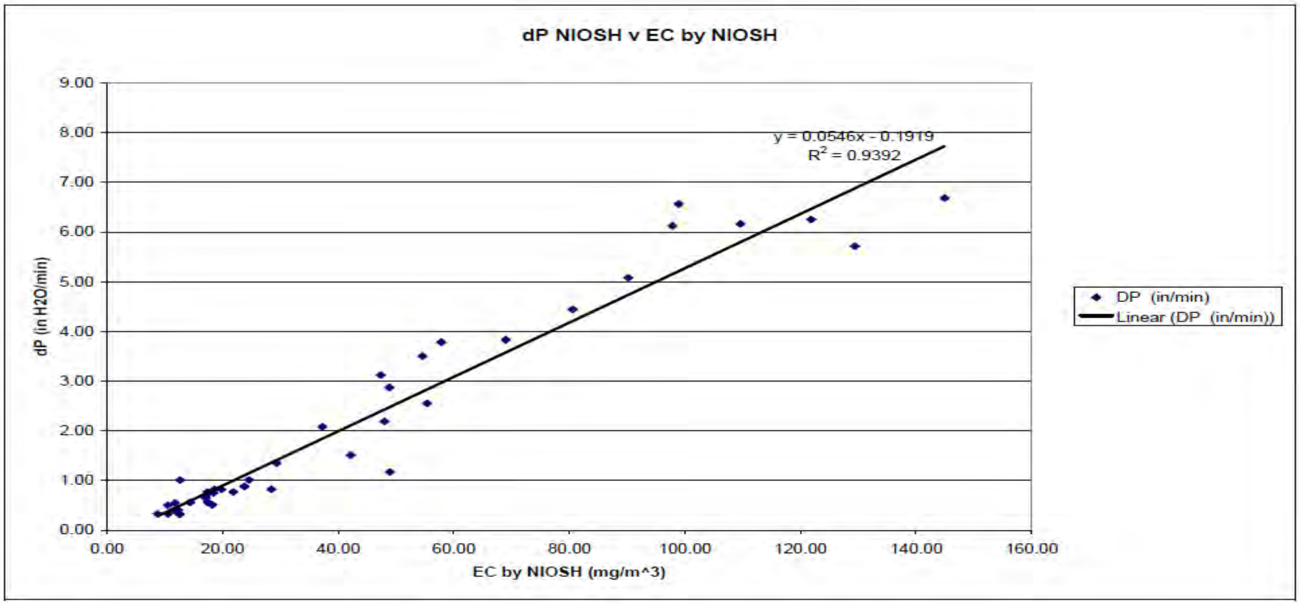
J3 DPI or DMR
Jen, 9/14/2015



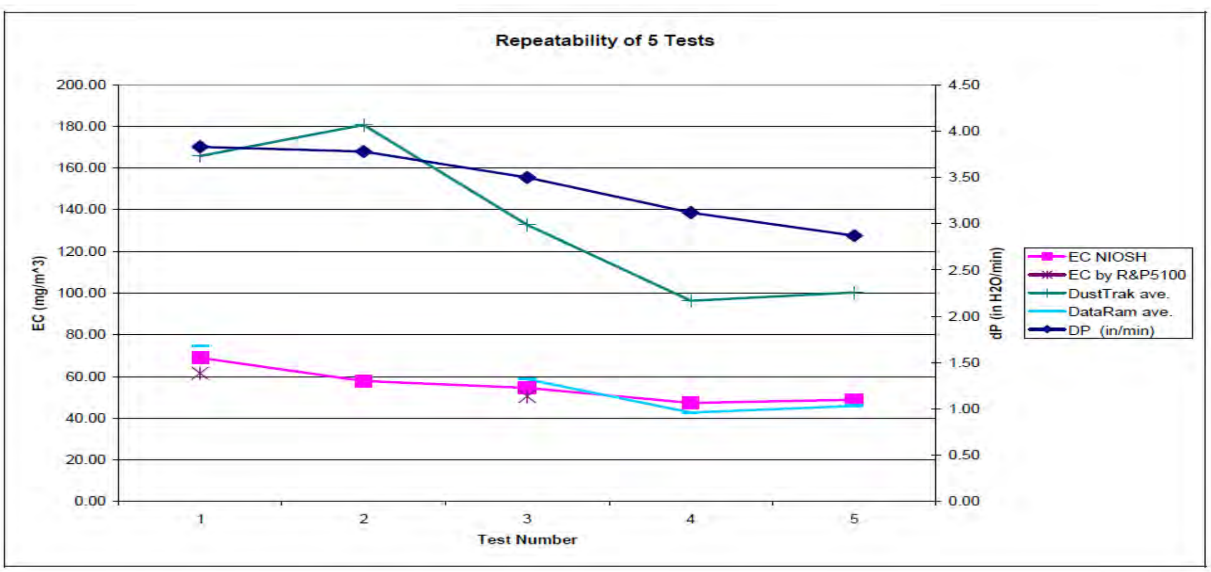
(CSHST Report 2004)



(CSHST Report 2004)



(CSHST Report 2004)



(CSHST Report 2004)

2004 – 2012

- Introduction of the AQT LLS device
- Introduction of the MAHA 4M LLS
- Phasing out of AQT and replacement with AVT 530
- Standardised load procedure introduced (20/20/20 seconds)

Air Quality Technologies (AQT)

Source: B Davies

MAHA 4 M

Source: MAHA Pty Ltd Marketing Documentation 2013

AVT 530

Source: Kenelec Scientific Pty Ltd d Marketing Documentation 2013

2004 – 2012 Cont

- Sample collection at tailpipe (including vehicles fitted with water based conditioning tank)
- Period of uncertainty in results especially between different testing organisations
- Reporting of results by some testing organisations to 0.001 mg/m^3 EC

2004 – 2012 cont

- Concern within maintenance managers as to value of testing
- Introduction of requirement to maintain engines at 15% of baseline test (or 30% for new generation engines)
- Lack of understanding of uncertainty of analysis causes confusion

University of Wollongong (Davies 2013)

- Coal Services Health & Safety Trust Grant
- All portable monitoring devices available to the industry at that time suffered from the fact that they cannot be easily calibrated to an internationally accepted standard
- Most light scattering devices are calibrated to an internal standard (light block), a similar instrument (gold standard instrument) or an aerosol totally different to DP

University of Wollongong (Davies 2013)

- This lack of an agreed calibration procedure results in a significant level of variability of raw exhaust DP emission analysis depending on the type of instrument used
- This in turn leads to confusion as to how operations should proceed so as to control raw exhaust DP emissions

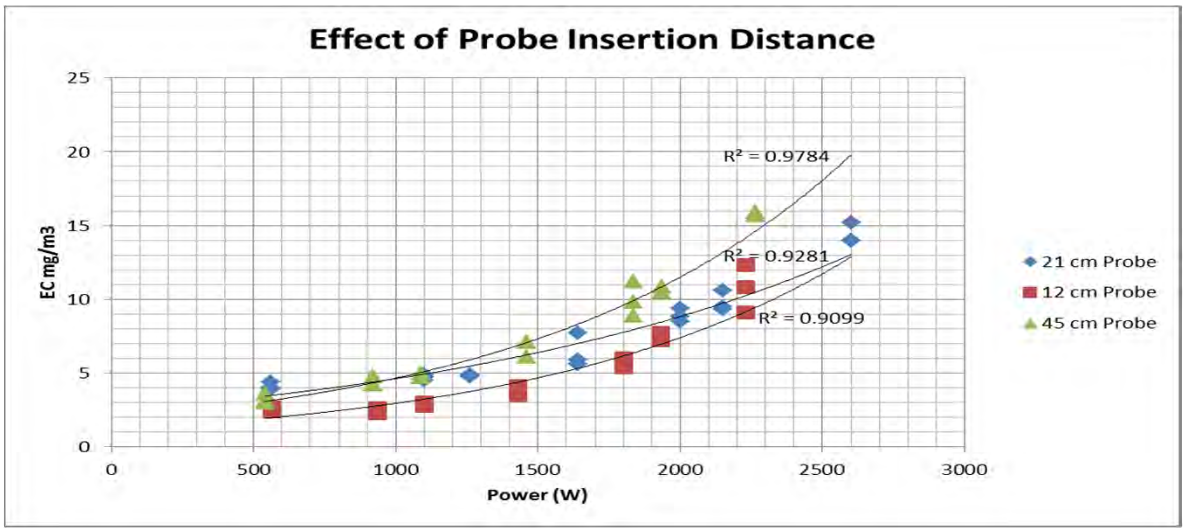
Coal Services Health & Safety Trust Project

- To develop a practical means by which portable DP analysers could be independently calibrated to the same universal standard (NIOSH 5040)
- This in turn would allow mine engineers to have confidence in raw exhaust DP results so as to implement & maintain controls with a resultant lowering of atmospheric DP levels

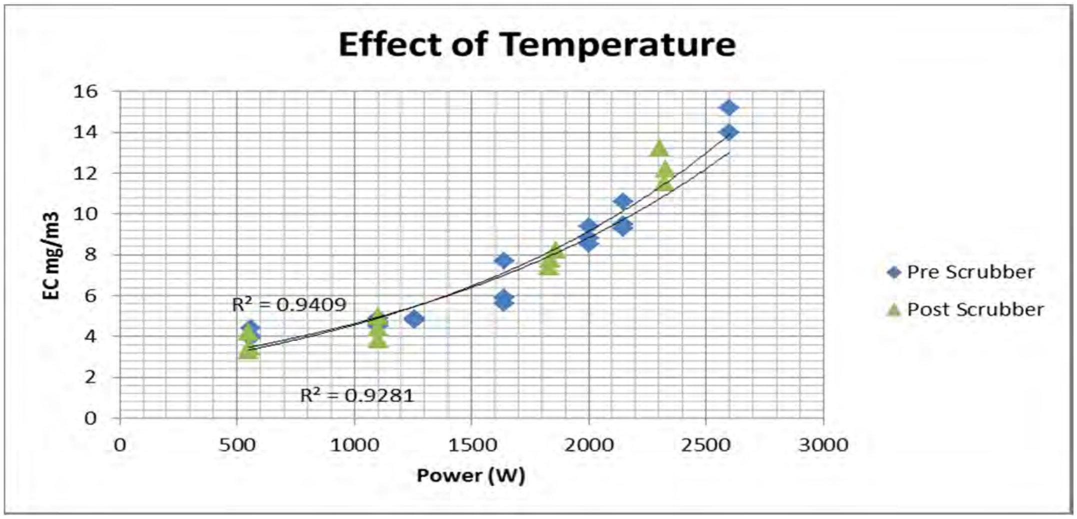
Research Method

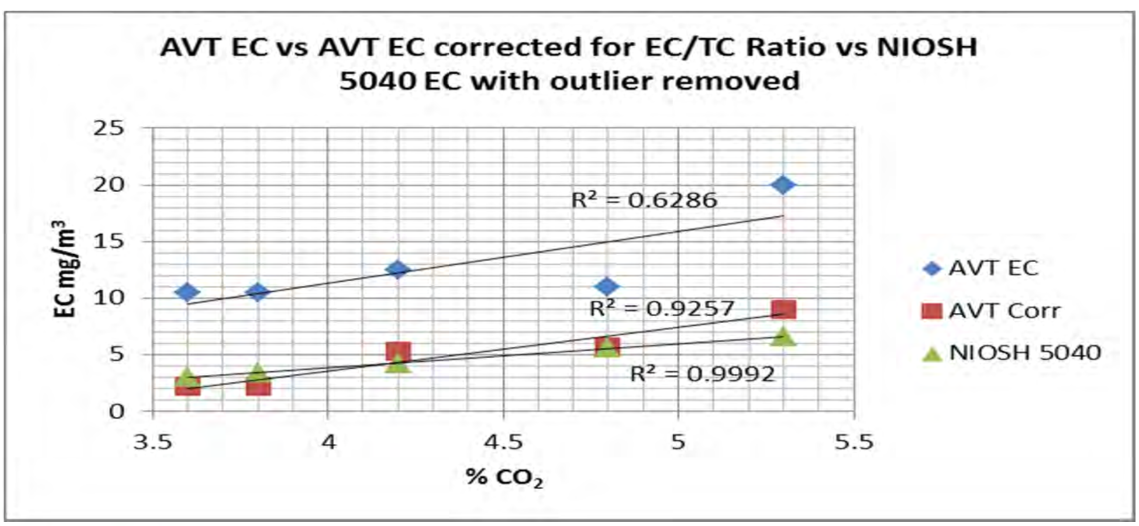
- Design & build a small DP source that is cheap & portable to be used by monitoring organisations
- Develop a test procedure & validate the system to a standard method (NIOSH 5040)
- Compare different direct reading instruments to evaluate accuracy & precision

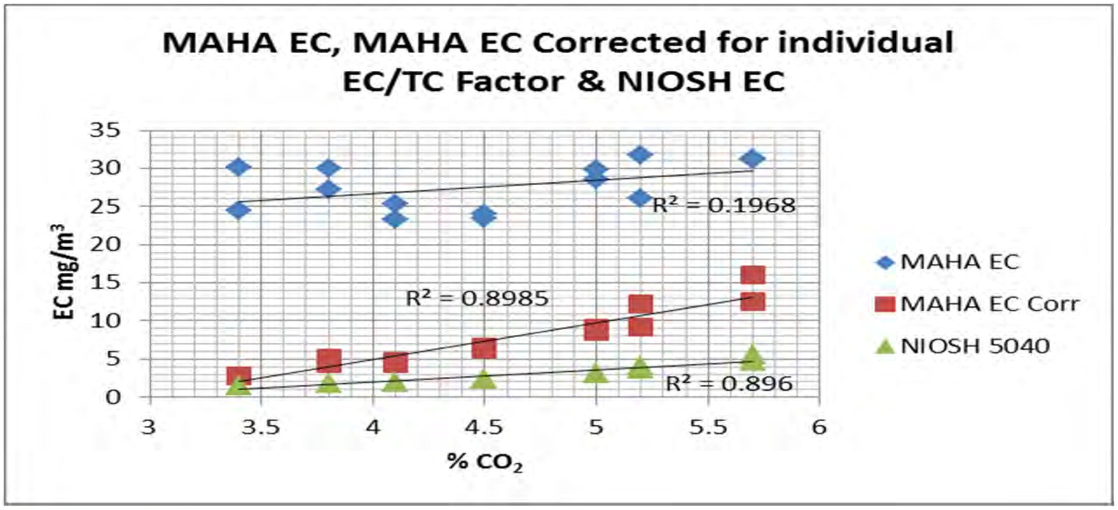
Diesel Particulate Source



© B Davies - 2015


Effect of Temperature
EC mg/m3
Power (W)
R² = 0.9409
R² = 0.9281
Pre Scrubber
Post Scrubber
0
2
4
6
8
10
12
14
16
0
500
1000
1500
2000
2500
3000


AVT EC vs AVT EC corrected for EC/TC Ratio vs NIOSH 5040 EC with outlier removed
EC mg/m³
% CO₂
R² = 0.6286
R² = 0.9257
R² = 0.9992
AVT EC
AVT Corr
NIOSH 5040
0
5
10
15
20
25
3.5
4
4.5
5
5.5



© B Davies - 2015

Sampling DP From the Statutory Gas Point

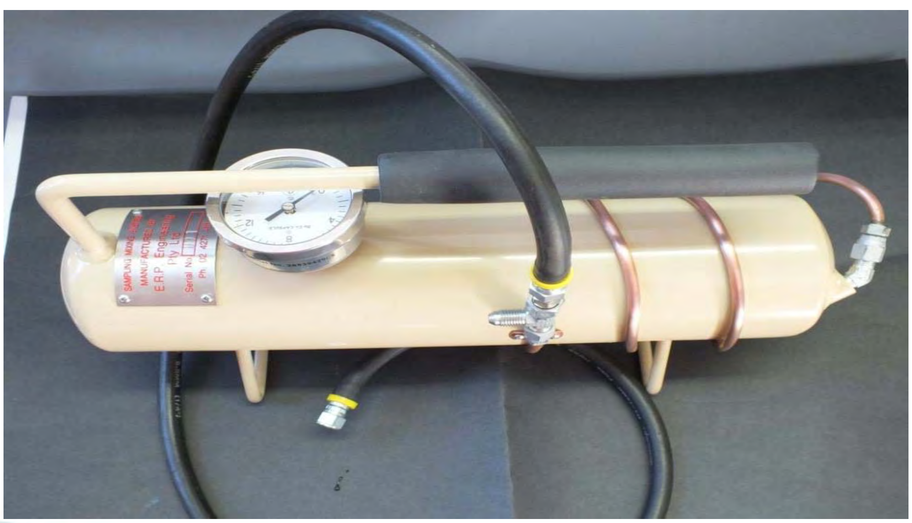
© B Davies - 2015

Data From Gas Sampling Point

Engine Type	Engine Status	LLS Device No. 1 EC mg/m³	NIOSH 5040 EC mg/m³	EC/TC Ratio
Cat 3306	Idle	2	5	0.55
Cat 3306	Load	12	12	0.67

Engine Type	Engine Status	LLS Device No.1 EC mg/m³	LLS Device No.2 EC mg/m³	NIOSH 5040 EC mg/m³	EC/TC Ratio
Cat 3126	Idle	25	8	13	0.53
Cat 3126	Constant Load	97	65	48	0.83
Cat 3126	Flight Revs	55	26	35	0.65

ERP Mixing & Cooling System

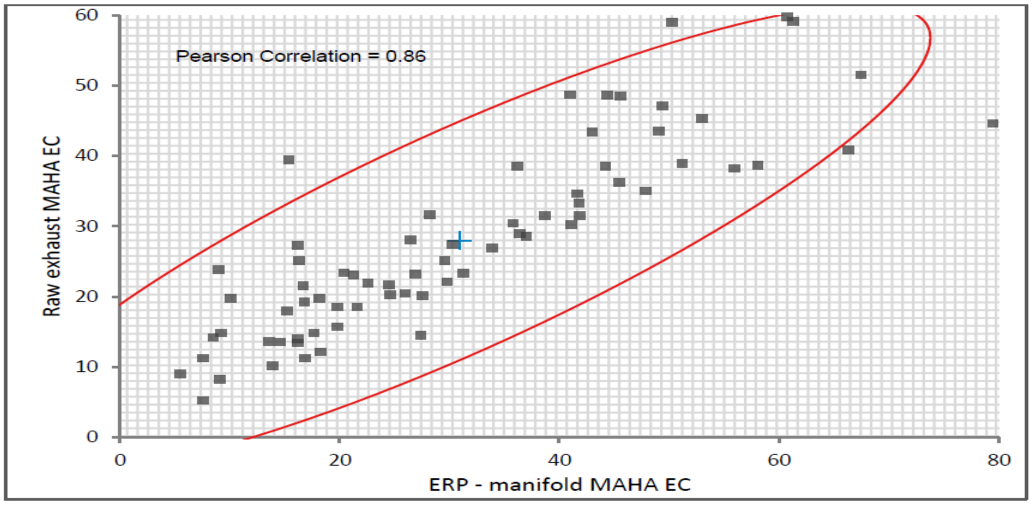


CSH&ST Project By Mason (2014)

- Acceptable correlation between samples collected at manifold (gas point) and tailpipe
- Current correction factor for MAHA MPM-4M requires updating from 0.46 to 0.65 when sampling from the exhaust and 0.67 from the manifold
- Sampling from manifold eliminates water issues from conditioner tanks, control over probe position & insertion and more realistic data for emissions management

Engine type	Manufacturer	No. tested
3126	CAT	1
3304	CAT	1
3306	CAT	3
1006-6	PERKINS	45
1104C-44	PERKINS	2
4.10 TCA	MWM	1
6V92	DETROIT	1
C7	CAT	13
D916-6	MWM	3
	Total engines tested	**70**

Comparison of Tailpipe vs Manifold (Gas Point)



(CSHST Report 2014)

Hines, Kon, Bartley & Davies 2014

- 2000 – NIOSH demonstrated relationship between differential pressure vs workplace respirable dust levels
- 2004 – extension of this principle developed by NIOSH & SKC Inc to measure DPM under field conditions
- Prototype device given operating name “Diesel Detective” and trialled in USA, Australia, Canada & South Africa

Background (cont)

- Australia study showed device had good potential as a survey type quality measurement instrument
- Device never commercialised due to sampling & filter issues
- Original patent lapsed in Australia on 7th July 2013

Principle of ChekMate®

- Raw exhaust sampled at the manifold, cooled and mixed (ERP Mixing & Cooling System)
- Measure the back pressure across a quartz filter before and after 1.5 L (or 2.5L) sample of exhaust is drawn across the filter
- The change in backpressure (Δp) is calibrated against NIOSH 5040

Diesel ChekMate®

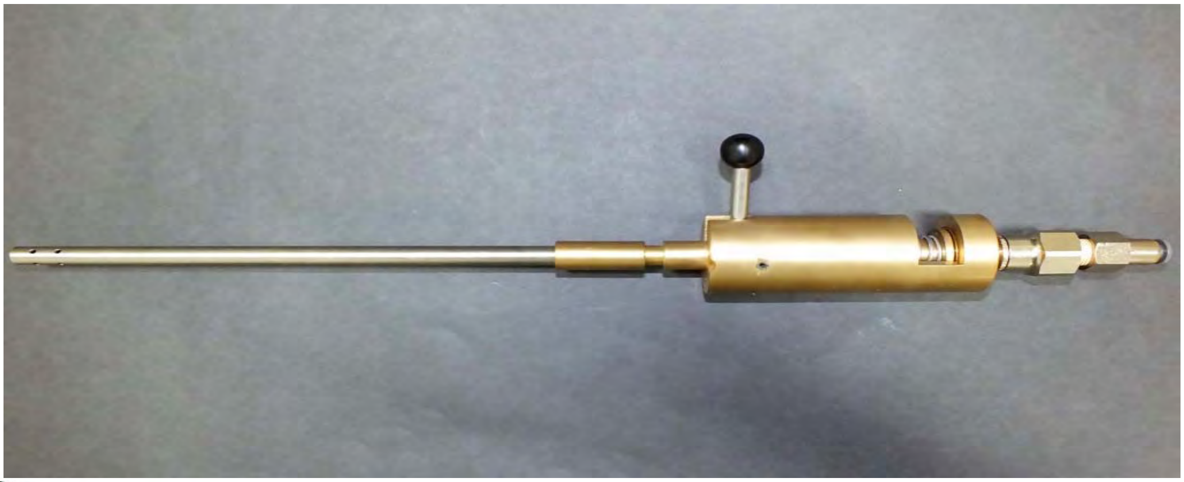
Design of Diesel ChekMate®

- Focus on simplicity & robust design for use in workshops by diesel mechanics
- Calibrated against NIOSH 5040 using 71 in-field engine samples from both coal & metaliferrous mining industry (14 different engine types)
- Operating ranges
  - Low: 2 – 14 mg/m^3 EC in raw exhaust
  - High: 14 – 60 mg/m^3 EC in raw exhaust

Design of Diesel ChekMate®

- Following feedback from operations the ChekMate® has been fitted with a flow control solenoid, linked automatic timer & pendant control system for single person operation
- Patent granted in Australia and pending in Canada & South Africa

ChekMate® Probe & Filter Holder

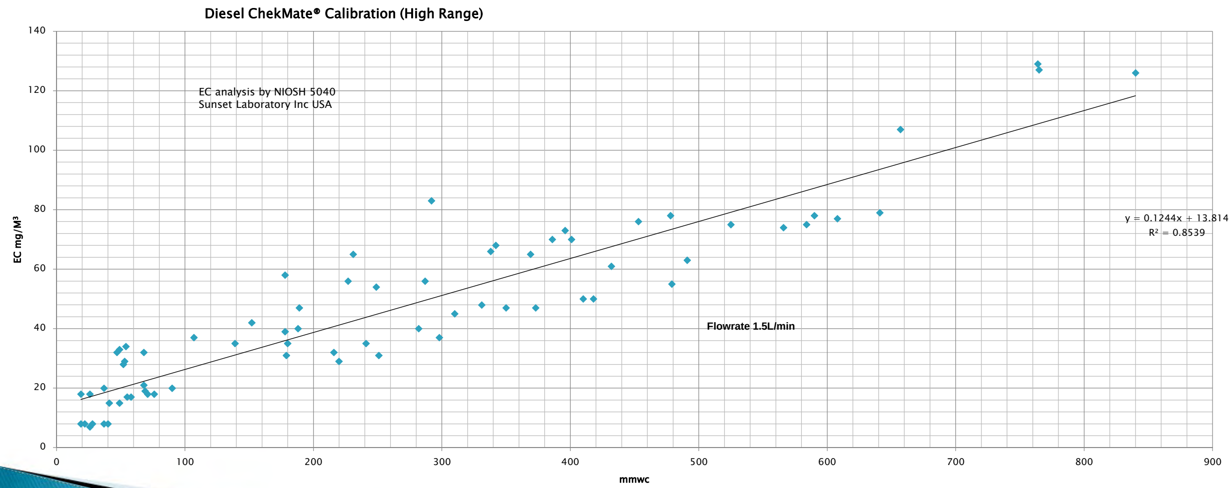


Loading Filter into Probe

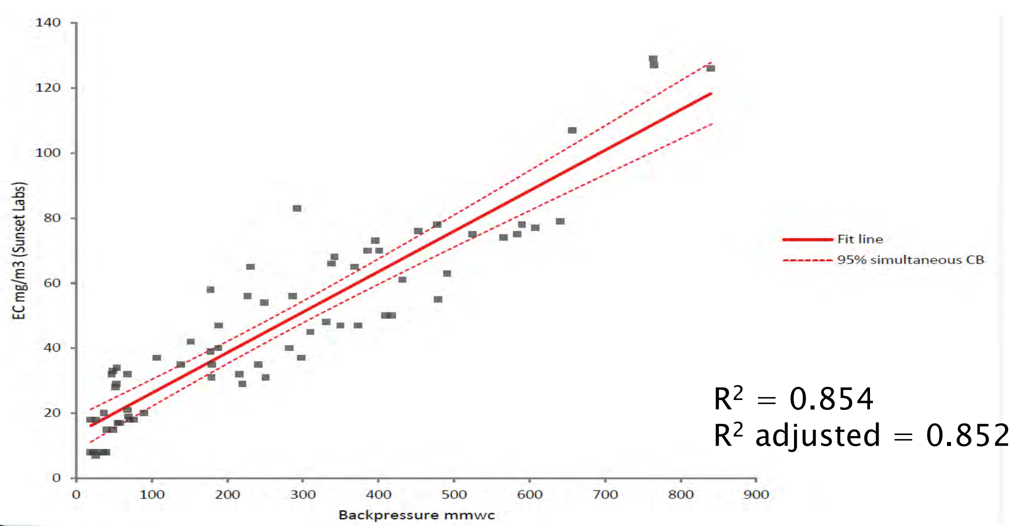
Sampling System & Probe Connected to Engine Exhaust System

© B Davies - 2015

ChekMate® Calibration Curve
71 Samples from In-Service Engines

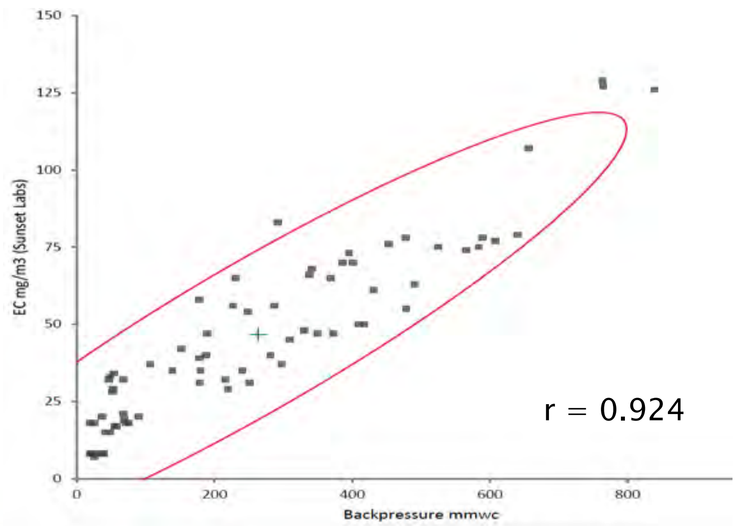


Linear Regression with 95% Confidence Bands

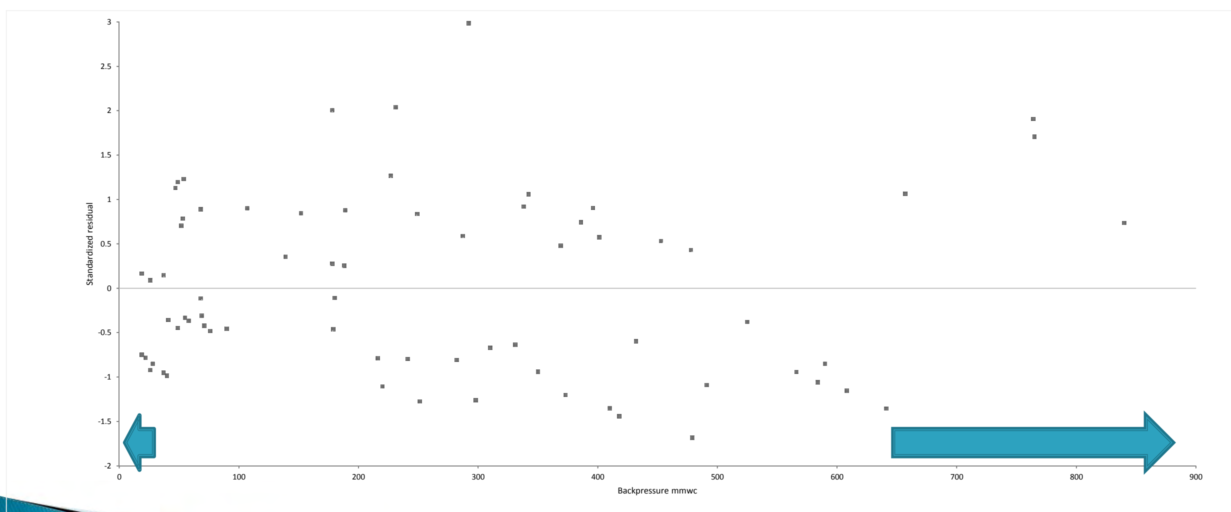


$R^2 = 0.854$
R^2 adjusted = 0.852

Pearson Correlation with 95% Confidence Bands



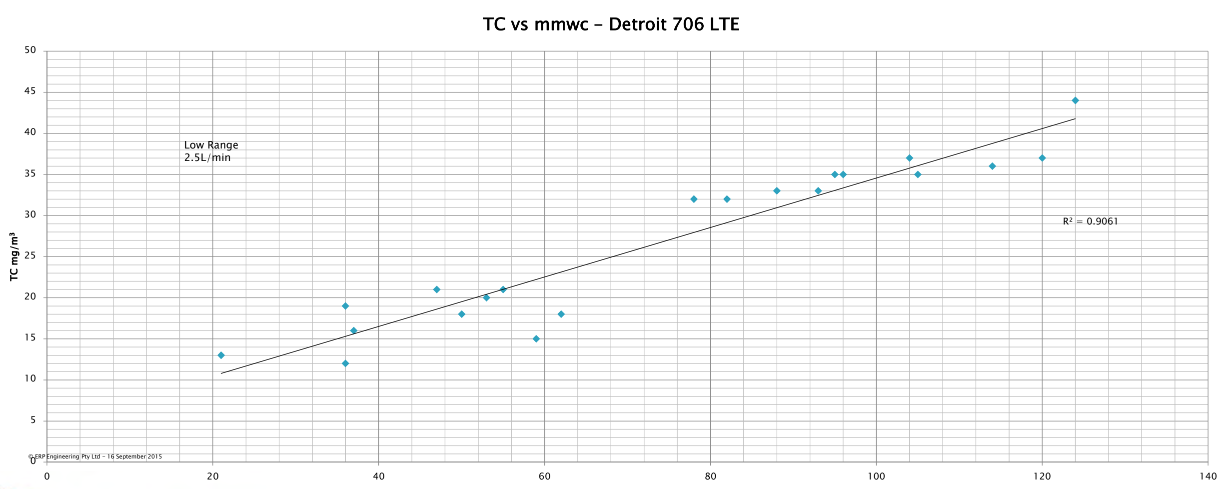
Residuals



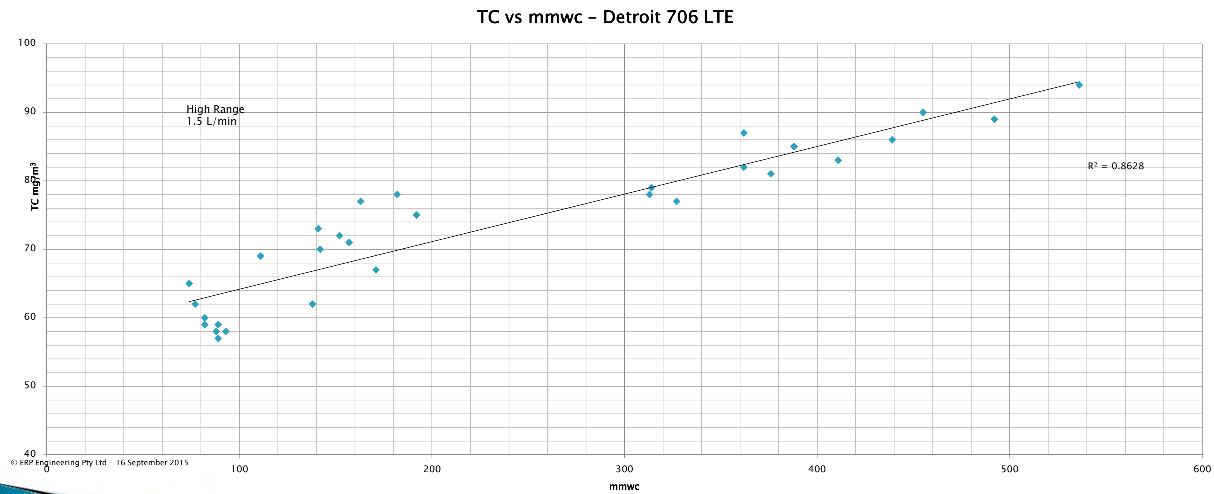
Other Options

- Possible to calibrate for TC but as not used in Australia has only been done under steady state conditions
- Potentially could be done under transient conditions if there was a need to do so

Low Range TC – Steady State



High Range TC – Steady State



EC via NIOSH 5040 in Raw Exhaust

- The analysis of EC in raw exhaust by NIOSH 5040 presents some unique analytical issues
- The filter loading is generally well above the 20ug/cm^2 maximum stated in NIOSH 5040
- The use of the laser cut point (OC/EC) in the instrument can lead to incorrect results due to the high filter load

EC via NIOSH 5040 in Raw Exhaust

- Best approach is to take cut point when oxygen is introduced into the system
- The analytical uncertainty for raw exhaust samples is much higher than atmospheric samples due to the high filter load
- Analytical uncertainty can be as high as ±12%

Uncertainty of Measurement vs Baseline Requirements

- In NSW, QLD & WA there is a guideline requiring mines to maintain raw exhaust EC levels to ±15% of the baseline values (older style engines)
- Given the analytical uncertainties involved in the measurement (analysis, volume & time) there is a high probability that the guideline requirement cannot be achieved for many engines.

Uncertainty of Measurement vs Baseline Requirements

- This uncertainty (and the lack of a standard sample collection method) gives rise to a high level of variability in results with resultant confusion as to what result is correct
- Need for uncertainty in measurement technique to be considered when setting baseline requirements

Limitations of ChekMate ®

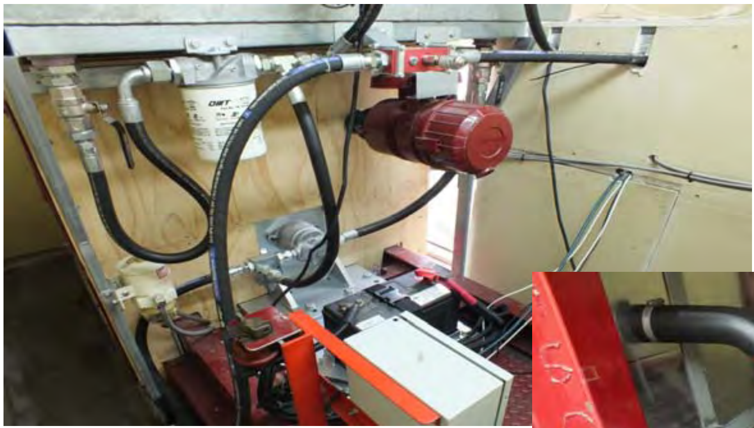
- Engine exhausts with very high organics (grossly over fuelled) can give high results due to blockage of filter causing increased back pressure. The presence of over-fueling can easily be identified by gas analysis
- Uncertainly of results ± 15% which is adequate for a screening device

Hines & Davies 2015

- Arranged a comparison trial involving the three different devices used in Australia to measure raw exhaust DPM
- Since that trial have been working with PM-Tech (MAHA) to standardise calibration process

ERP Pty Ltd – Test Rig

DPM Source – Detroit 706 LTE



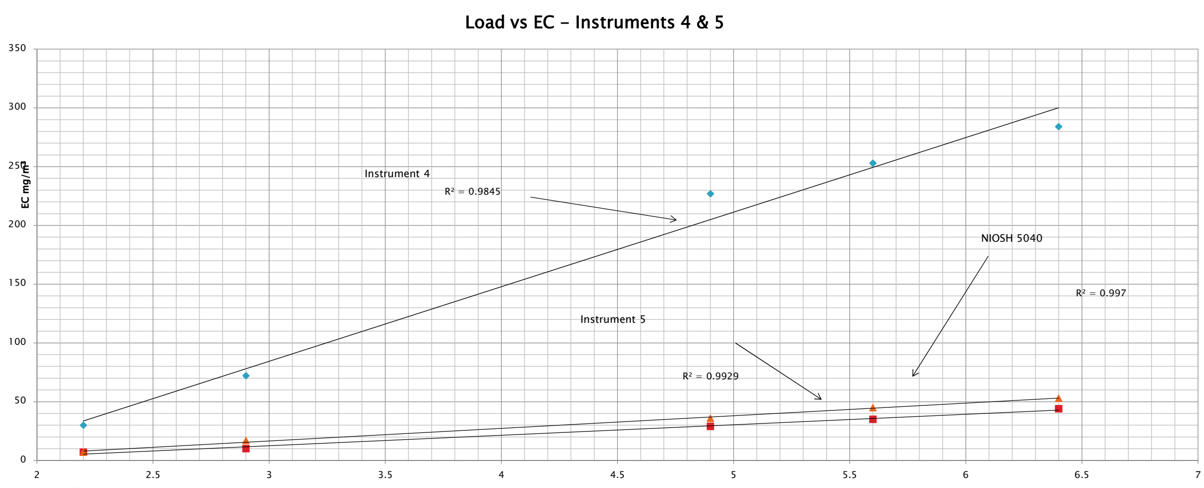
Sampling Protocol

- Steady state load at five different levels
- CO_2 measured continuously to monitor engine load stability
- Sampling from before any control technologies
- Used ERP mixing unit
- NIOSH 5040 samples collected in two ways
  - ChekMate filters (25 mm quartz filters)
  - High flow sampling pump on 37mm SKC DPM filter cassettes

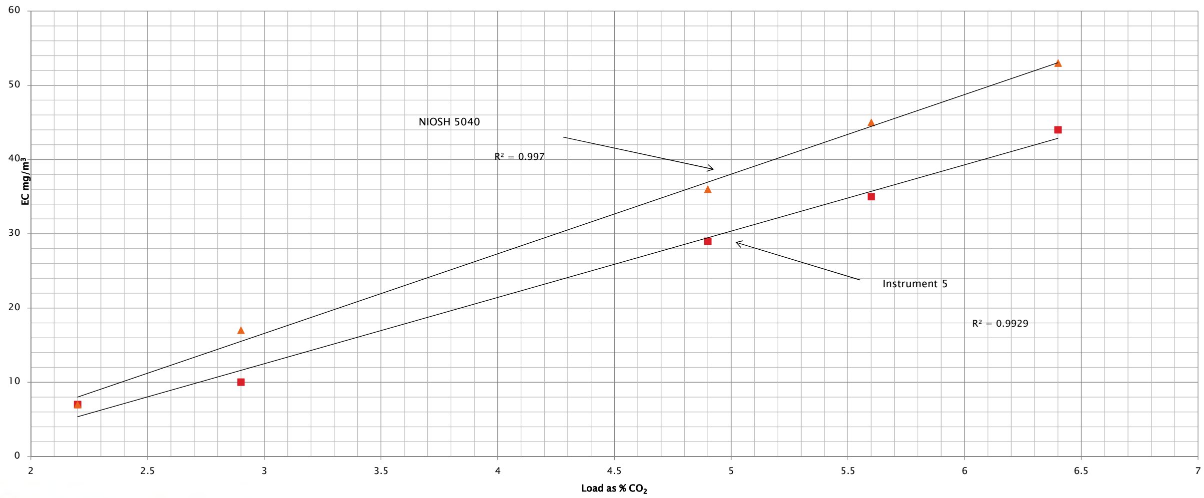
Instruments Tested

Instrument Model	Serial Number	Date Last Calibrated	Project Identification
AVT 530	Not Available	1 May 2014	Instrument (1)
AVT 530	0106/8530128408	6 June 2014	Instrument (2)
AVT 530	71002264	7 January 2015	Instrument (3)
MAHA – 4M	536034-001	1 May 2015	Instrument (4)
MAHA – 4M	537165-004	4 May 2015	Instrument (5)
ChekMate	CM 001	13 May 2015	Instrument (6)
ChekMate	CM 005	13 May 2015	Instrument (7)

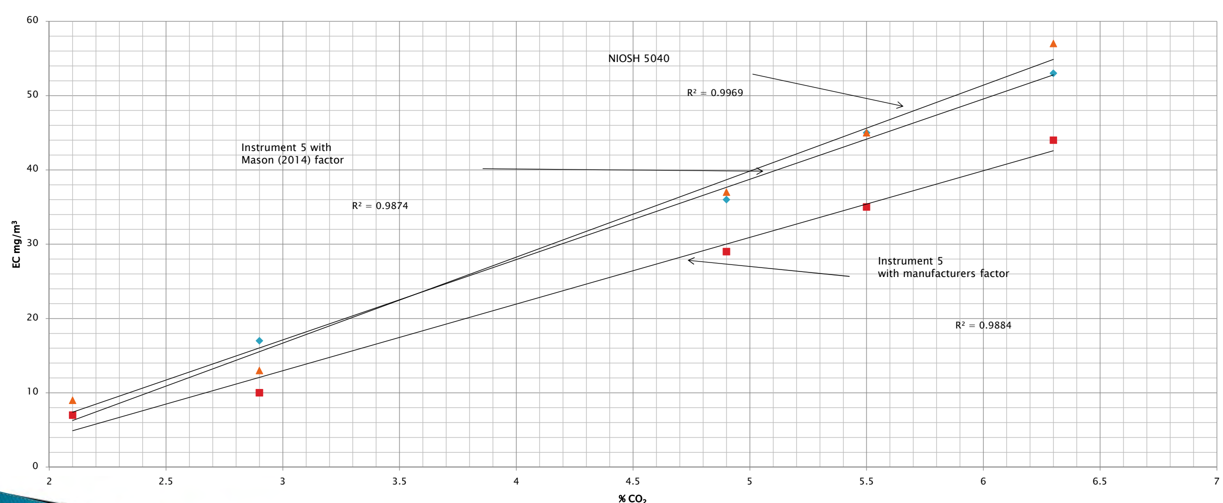
Instruments 4 & 5 vs NIOSH 5040



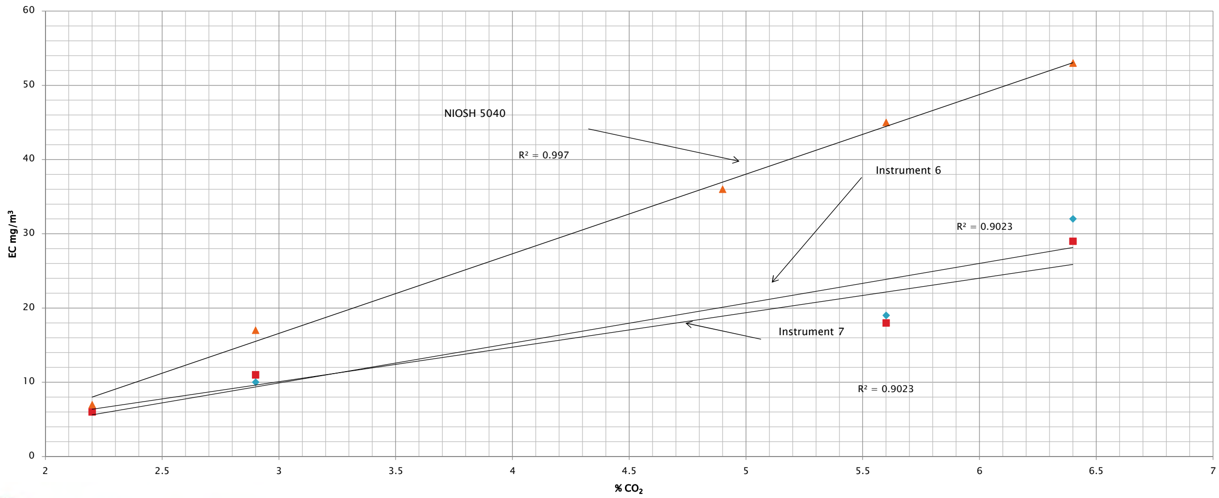
Instrument 5 vs NIOSH 5040



Instrument 5 vs NIOSH 5040 using Manufacturers & Mason (2014) Factors



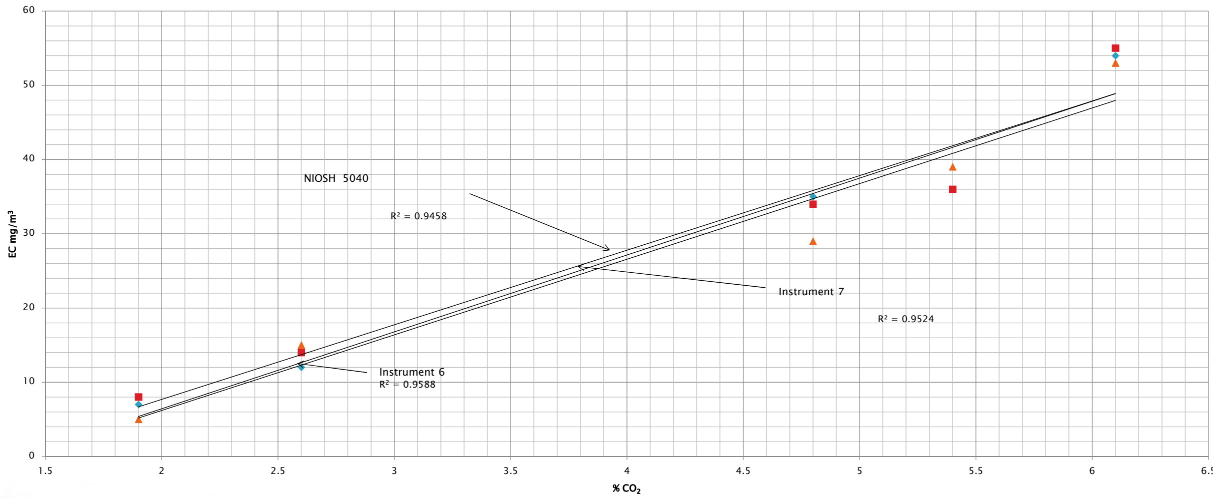
Instruments 6 & 7 vs NIOSH 5040



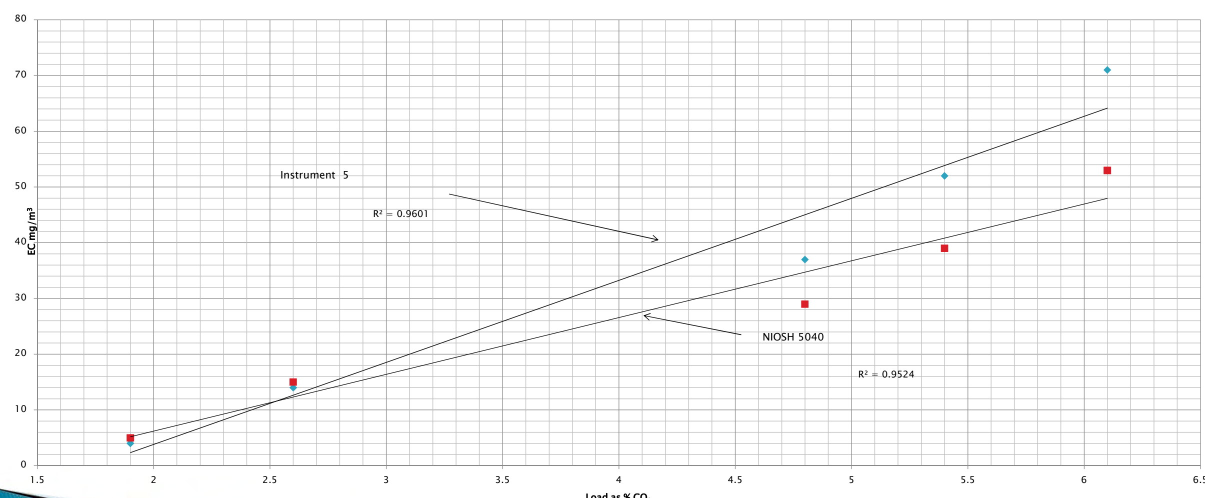
Calibration of ChekMate (Instruments 6 & 7)

- Had been done on in-service engines using a transient test procedure
- Separate steady state calibration developed and instruments retested against instrument 5 & NIOSH 5040
- Instrument 5 swamped with water day before trial and not recalibrated by operator

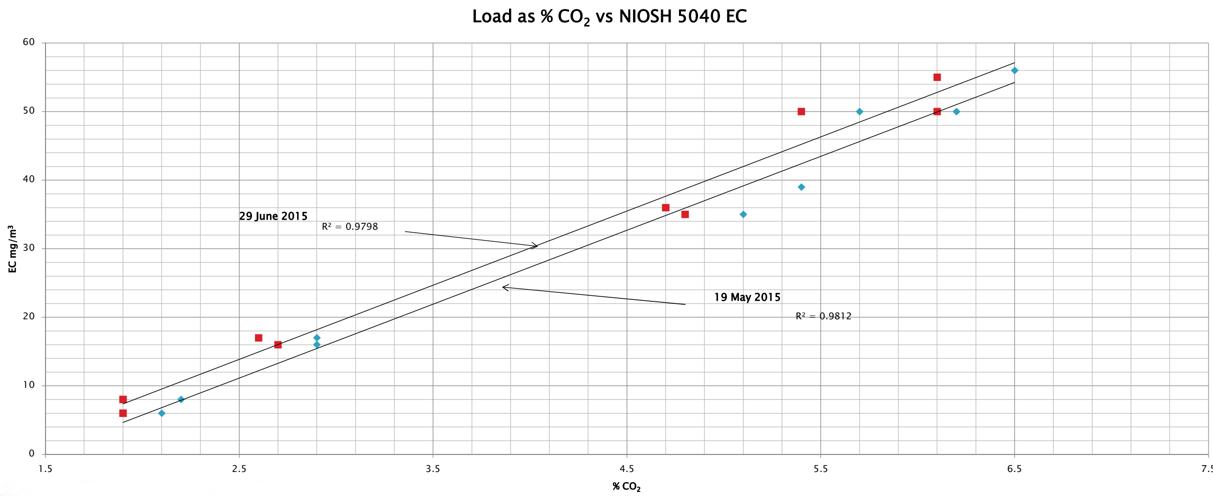
Instruments 6 & 7 vs NIOSH 5040 on 29 June 2015



Instrument 5 vs NIOSH 5040 on 29 June 2015



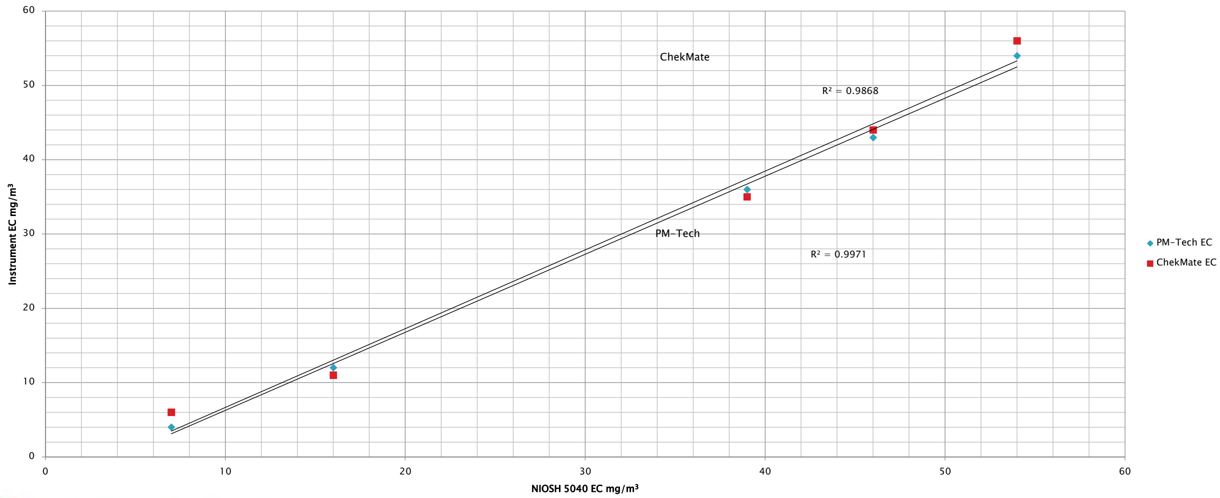
Engine Load 19 May vs 29 June



Calibration Collaboration

- Resulting from calibration project in May & June 2015 agreement between PM – Tech (MAHA) and ERP Engineering (ChekMate) to jointly compare instruments
- Resulted in both companies instrumentation being calibrated to the same international standard (NIOSH 5040) at same time
- Major step forward in standardising testing procedures

PM-Tech (MAHA) & ChekMate vs NIOSH 5040 Post MAHA Re-Calibration on 9 September 2015



Outcomes

- All instruments must be calibrated on the same engine load basis as routine testing
- Instruments 5, 6 & 7 showed good correlation to NIOSH 5040 if the appropriate factors were used and in good working order
- Instruments 2 & 3 need review by their manufacturer

Concluding Remarks

- It is possible to measure raw exhaust DPM
- To do this a standard method of sample collection is required
- Sampling from the manifold is a better option when looking at maintenance issues (not masked by control technologies)
- Calibration of instrumentation is a major issue but can be overcome with co-operation between manufacturers

Concluding Remarks (Cont)

- Calibration must be on the same basis as testing (i.e. either steady state or transient)
- Uncertainty of sampling & analysis must be understood and considered when setting statutory requirements

Acknowledgements & Contact Details

- The many people who have contributed to this story over the past 15 years

- Dr Brian Davies AM
  Honorary Principal Fellow
- University of Wollongong

- Email:
  bdavies@uow.edu.au
  or
  b.davies07@bigpond.com

© B Davies - 2015

DPM workshop

Dekati Ltd. - diesel particulate matter sample conditioning and measurement

Content

- Dekati company and products
- Dekati instrumentation for measurement of diesel particulates
- Possibilities in sample conditioning
- What you should consider when doing diesel particle measurements?
- Possibilities with measurement instruments

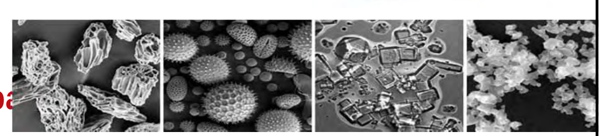
Dekati Ltd.

- Company founded in 1993
- Privately owned technology spin-off from TUT Aerosol Physics Lab
- Core competence and know-how
  - Fine particle sampling and measurement technologies
- ~ 20 highly educated employees
  - In-house R&D
  - Production
  - Sales & Marketing
  - Administration
- Exports ~ 95 % of sales
  - Distributors in ~35 countries worldwide
  - Thousands of instruments sold

DEKATI

What do we do?

- Instrumentation for fine particle sampling and dilution for demanding measurements
  - e.g. different parts of the power plant or engine exhaust
- Accurate Instrumentation for high-end partic measurements <10 µm
  - Particle concentration
  - Particle size distribution
  - Advanced particle properties
    - Electrical charge
    - Chemical composition
    - Shape and structure



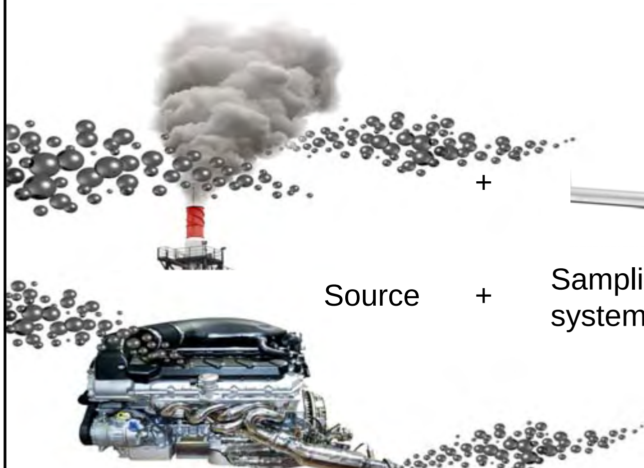
Dekati is one of the world's leading compa in advanced particle measurements

Dekati® Product Line for diesel PM measurements

- Real-time instruments
  - ELPI+™
  - High Temperature ELPI+™
  - High Resolution ELPI+™
  - DMM-230
- Dekati® Impactors
  - Dekati® Low Pressure Impactor DLPI+
  - Dekati® Gravimetric Impactor (DGI)
- Sample conditioning devices
  - Fine Particle Sampler FPS-4000
  - DEED, Dekati® Engine Exhaust Diluter
  - Dekati® Diluter
  - Dekati® Thermodenuder

DEKATI

Sample conditioning



Source +

Sampling line &conditioning system +

Measurement instrument

DEKATI

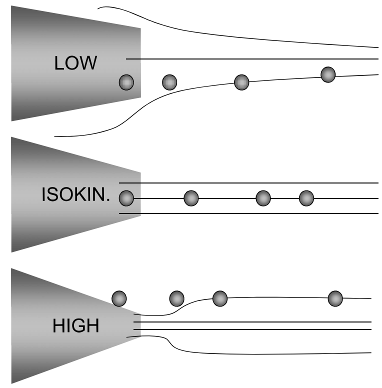
Jonna Kannosto

Isokinetic sampling

Flow speed in stack needs to match with flow speed in nozzle tip

- Too low flow speed in nozzle tip
  - Overestimates large particles
- Too high flow in probe
  - Underestimates large particles

Important if particles above 2.5 µm are to be mesured



DEKATI

Sample conditioning

Things you need to know!

Sampling dynamics

- Nucleation
- Condensation
- Evaporation
- Coagulation

Effect of dilution parameters

- Temperature
- Residence time
- Humidity
- Dilution ratio

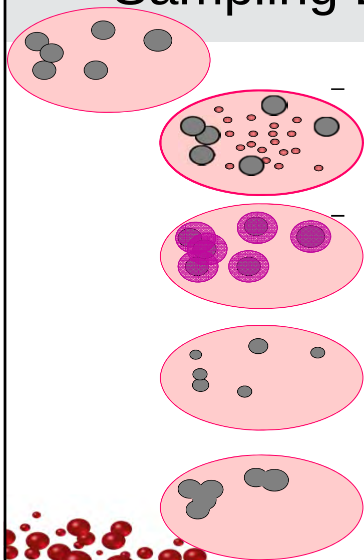
Particle Losses

- Inertial
- Gravitational
- Turbulent
- Diffusion
- Thermophoretic
- Electrophoretic

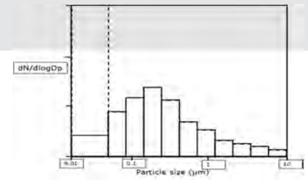
DEKATI

Jonna Kannosto

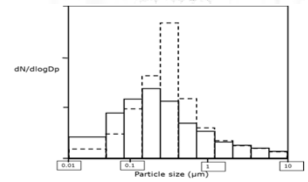
Sampling Dynamics



– Nucleation
  - New particles are formed
  - → Particle concentration increases

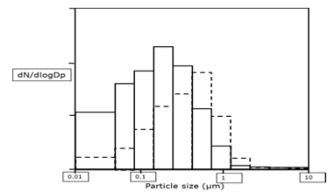


– Condensation
  - Vapor condense on surfaces and particles
  - → Particle composition changes and increases, water and moisture problems in sampling lines and measurement instruments



Evaporation
  - Volatile material evaporates from particles
  - → Particle composition changes, size decreases and particle number concentration may decrease

Coagulation
  - Two particles hit each other and formed a one new particle
  - → Particle concentration decreases, size increases and composition changes



Jonna Kannosto

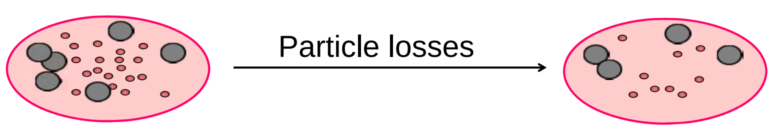
Sampling Dynamics

Particles can be lost easily

→ Number concentration decreases
→ Size distribution changes

Mechanisms

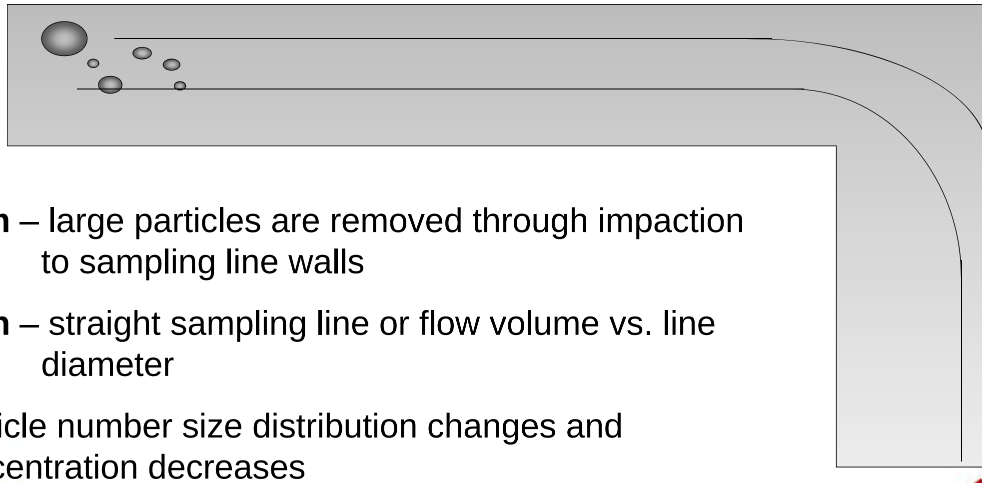
- Inertial
- Gravitational
- Turbulent
- Diffusion
- Thermophoretic
- Electrophoretic



DEKATI

Jonna Kannosto

Inertial impaction



Problem – large particles are removed through impaction to sampling line walls

Solution – straight sampling line or flow volume vs. line diameter

→ Particle number size distribution changes and concentration decreases

DEKATI

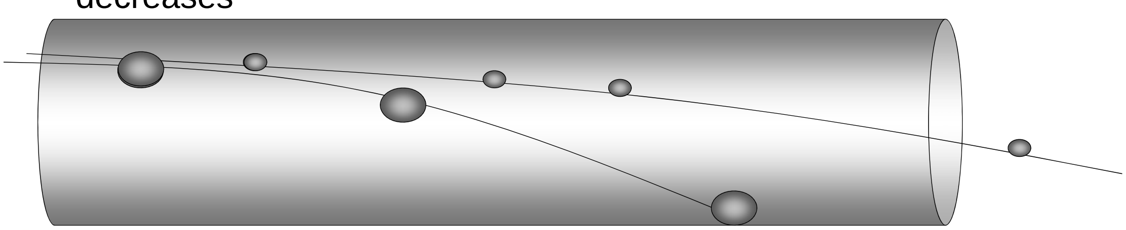
Jonna Kannosto

Gravitational losses

Problem – removes large particles by gravitational settling

Solution – short sampling lines, avoid long horizontal sections and residence time

→ Particle number size distribution changes and concentration decreases

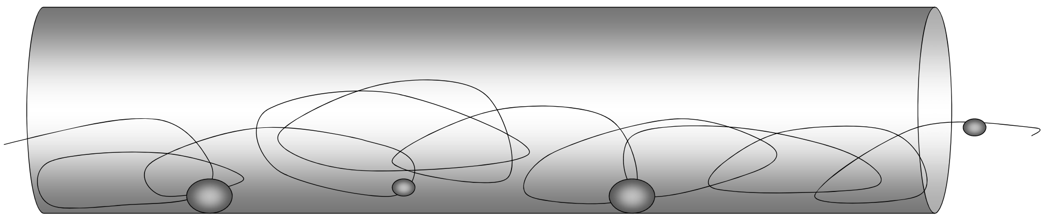


DEKATI

Jonna Kannosto

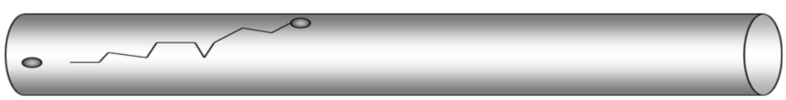
Turbulent impaction

Problem – large particles impact to sampling line walls due to turbulent flow patterns



Solution – Check the Reynolds number

Diffusion losses



Highly dependent on particle size, larger for small particles

Problem – small particles deposit through diffusion to sampling line walls

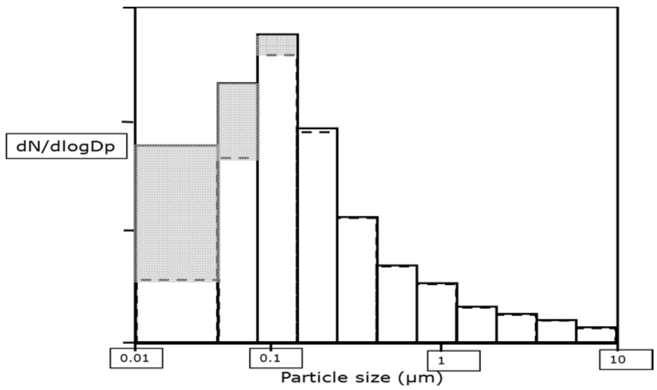
Solution – short sample transfer lines, laminar flow and short residence time

→ Particle distribution changes and concentration decreases

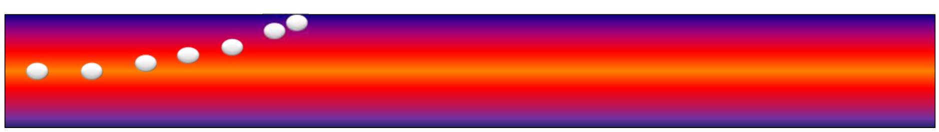
→ Main reason why PM exhaust samples cannot be stored

Diffusion losses

- Effect is highly dependent on particle size



Thermophoretic losses



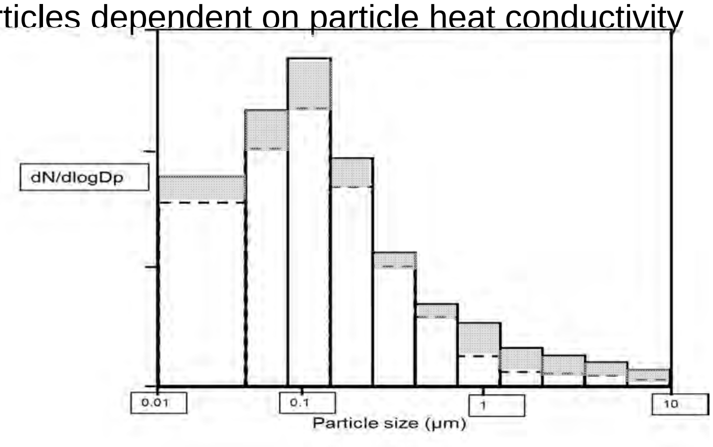
Problem - all particles are driven along a decreasing temperature gradient in gas

Magnitude dependent on temperature gradient and residence time

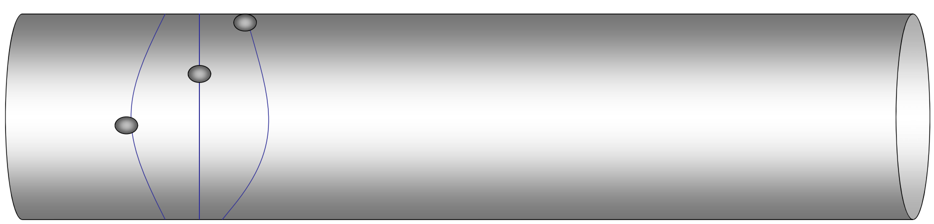
Solution – sample transfer line walls must be at sample temperature or higher

Effect of thermophoretic losses

- Effect not dependent on particle size for small particles
- For large particles dependent on particle heat conductivity



Electrostatic losses

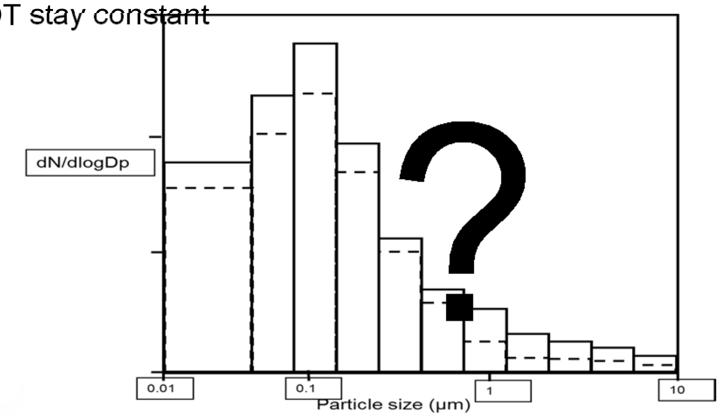


Problem - charged particles are driven to sampling line walls due to electric fields

Solution - use conductive material e.g. metal pipes. NO Teflon or silicon sample transfer lines or connectors

Effect of electrostatic losses

- Depends on charge/diameter ratio. If particles are uniformly charged depends on particle size, but generally this is not the case
- Does NOT stay constant



DEKATI

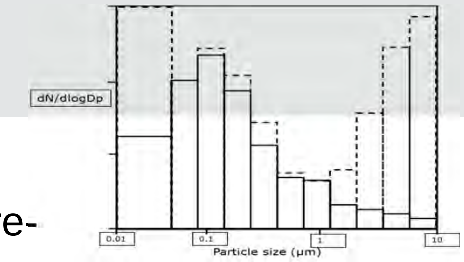
Losses - conclusions

- Transfer lines must be designed to suit the sample
  - Minimise length
  - Minimise residence time
  - Correct and preferably constant temperature of sample transfer lines
  - Conductive sample transfer lines

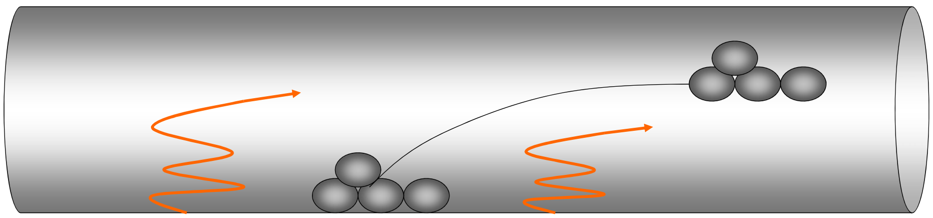
- Watch out for re-entrainment - sensible use of sample transfer lines

DEKATI

Re-entrainment



Problem - large particle clusters and volatiles re-entrain from sampling line walls



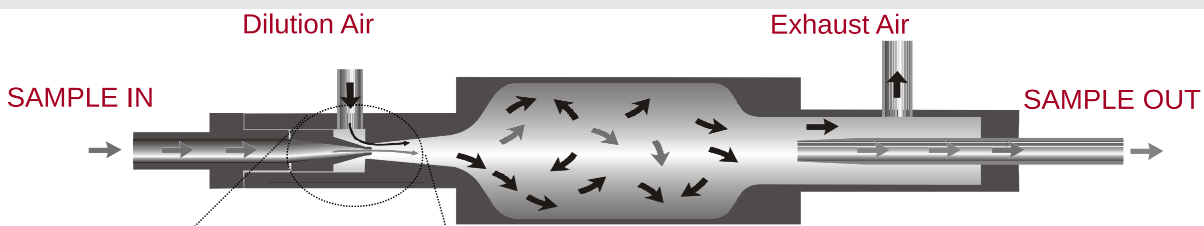
Solution - avoid losses and keep your sampling lines clean

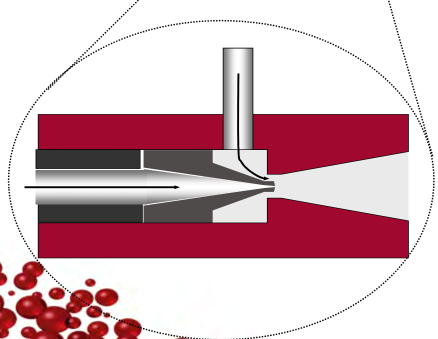
DEKATI

Dekati® Diluter and Double Diluter

DEKATI

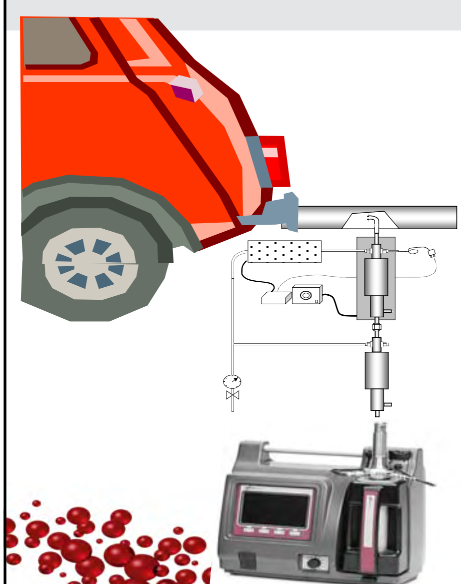
Dekati® Diluter

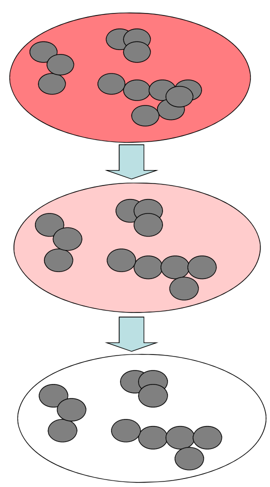




- Low pressure caused by dilution air flow in the nozzle sucks the sample from the inlet
- Mixing in the mixing chamber
- Coaxial dilution, low losses

Dekati® Double Diluter Setup





Tailpipe:

- High concentration
- High temperature
- High vapor pressure

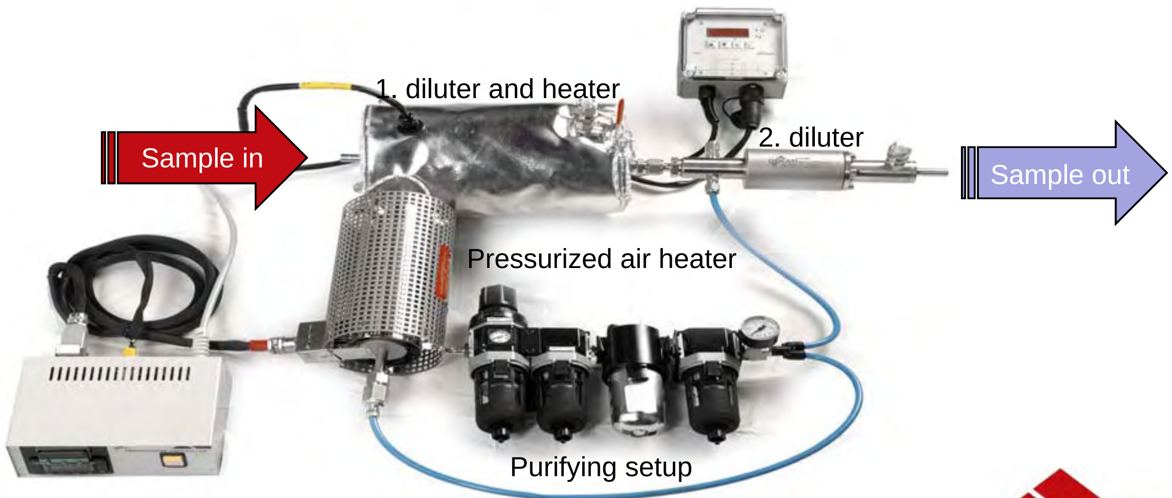
Hot Dilution

- Concentration decrease
- Vapor pressure decrease
- Temperature preserved

Cold Dilution:

- Concentration decrease
- Low vapor pressure => safe temperature decrease

Double Diluter setup



DEKATI

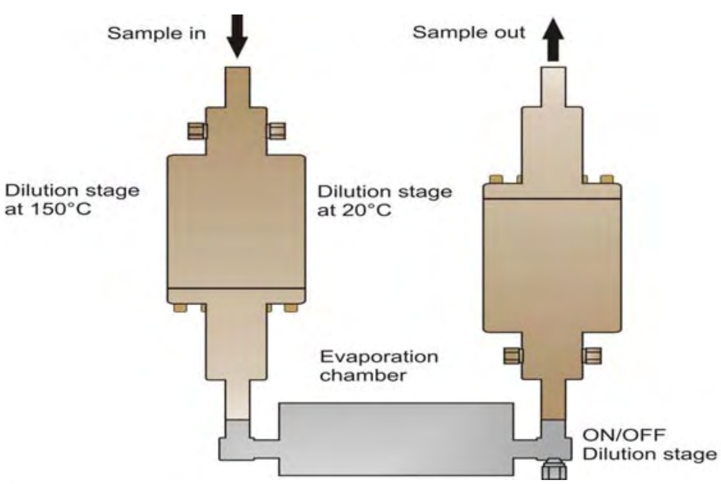
DEED

Dekati® Engine Exhaust Diluter

DEED
Dekati® Engine Exhaust Diluter

- Particle reduction factor
  - Low ~100
  - High ~1000
- Dilution system extremely robust - all stainless steel and no moving parts
- All specifications as recommended by PMP group
- Simple user interface
- Can be used with ANY particle number or mass measurement device

DEED Operation



FPS-4000

Dekati® Fine Particle Sampler

DEKATI

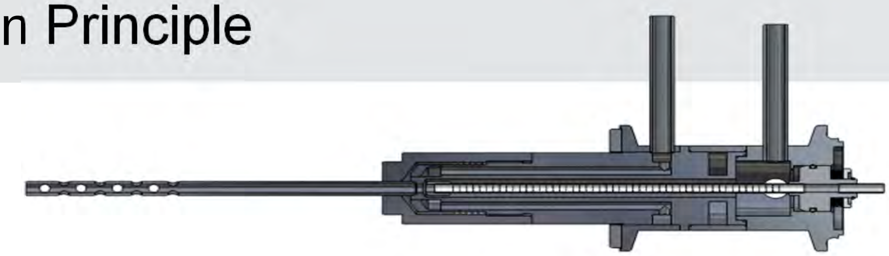
FPS: Fine particle sampler – Properties

- Controllable
  - Dilution temperature – cold/hot
    - 0-250(350)°C
  - Dilution ratio
    - 1:20(10)-1:200
  - Residence time
    - Residence time chamber & dilution ratio
- Measurements from low/high
  - Temperature 0-600°C
  - Pressure 750-2000 mbar abs
    - Trap studies
- Continuous dilution ratio calculation
  - +/- 10% reading
- Data recording
- Integration to data logging systems
  - Analog outputs/inputs

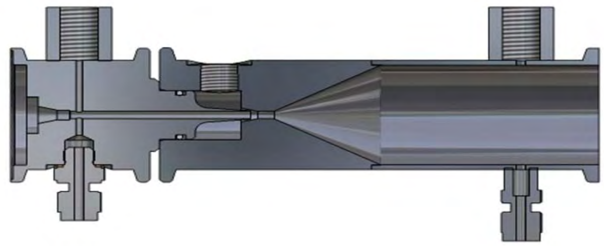
DEKATI

FPS Operation Principle

- Primary dilution
  - perforated tube dilution
  - Cold or hot primary dilution
  - Controlled dilution ratio



- Secondary dilution
  - Ejector type diluter acts as pump
  - Cooling of sample
  - Controlled dilution ratio



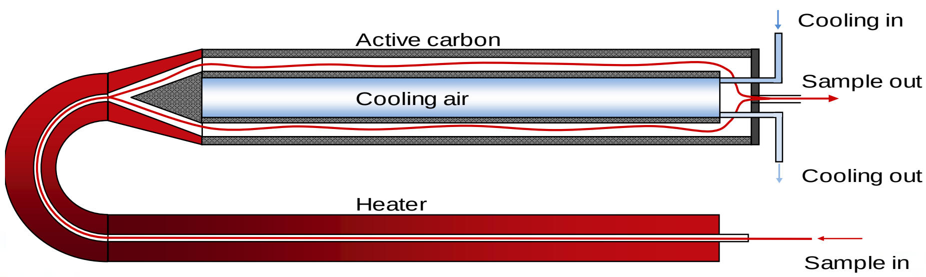
DEKATI

Dekati® Thermodenuder

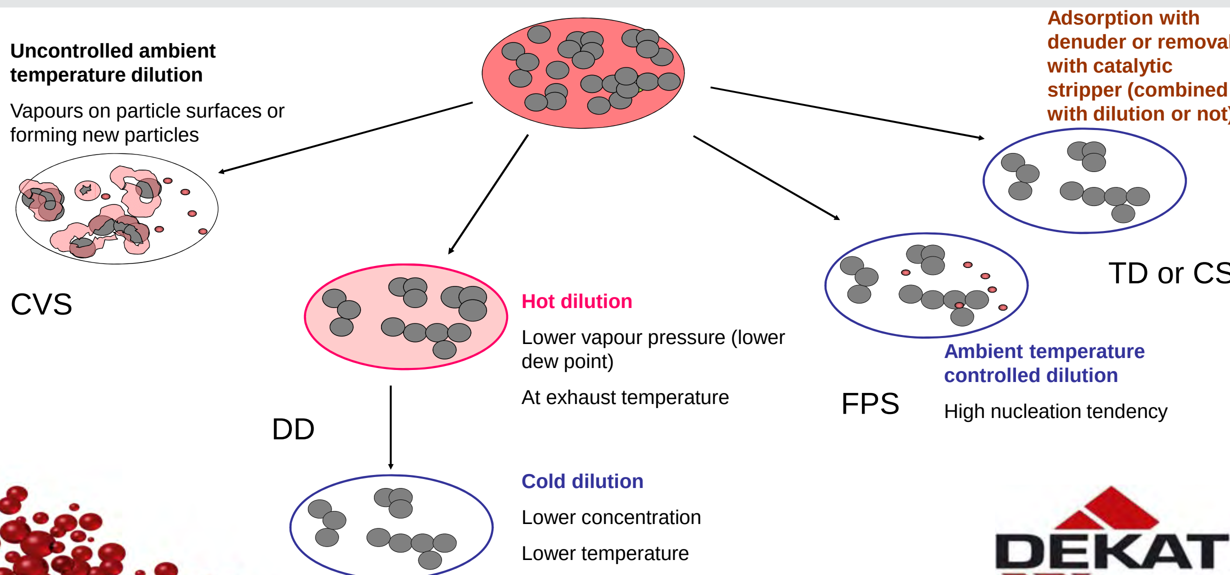
DEKATI

Design of Dekati® Thermodenuder

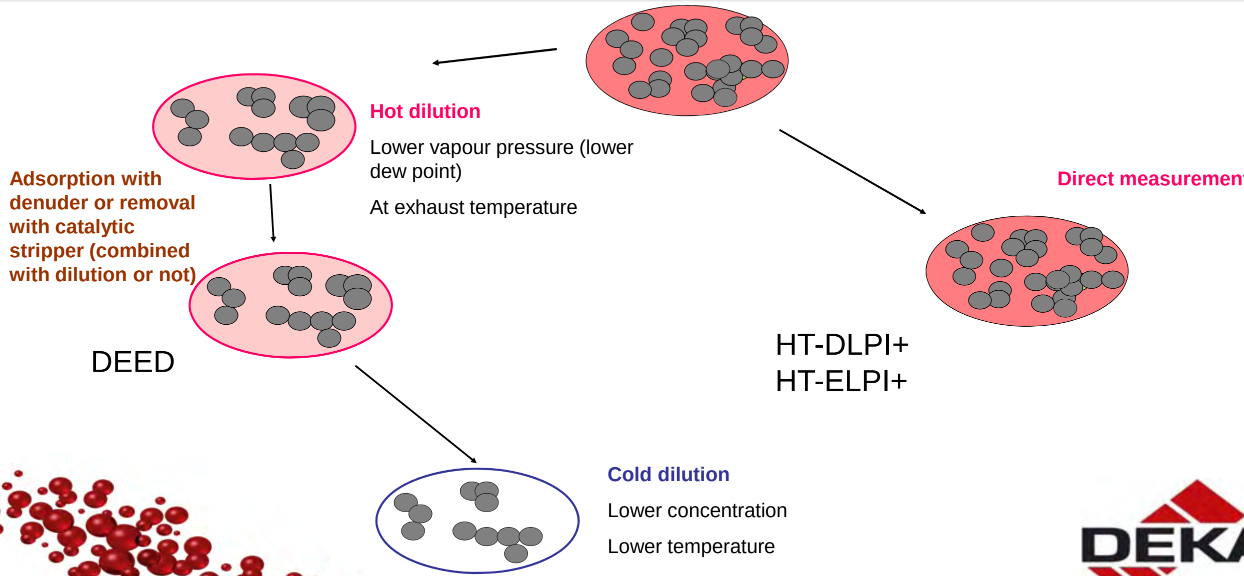
- Heats exhaust gases up to 250°C
  - most volatile components evaporate in vehicle exhaust
- Removes VOC with fibrous active carbon
- High volume flow rate, 10-20 LPM



Possibilities in treatment of volatiles



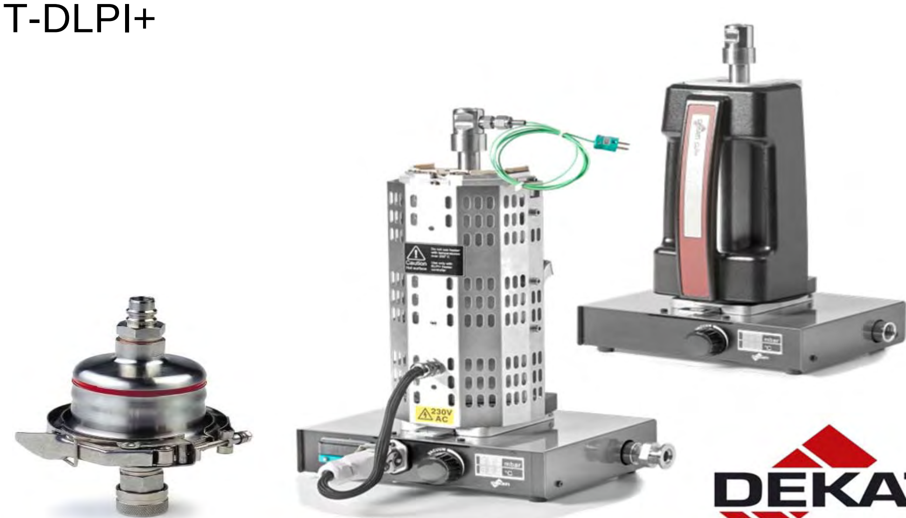
Possibilities in treatment of volatiles II



DEKATI

Dekati® Gravimetric Impactors

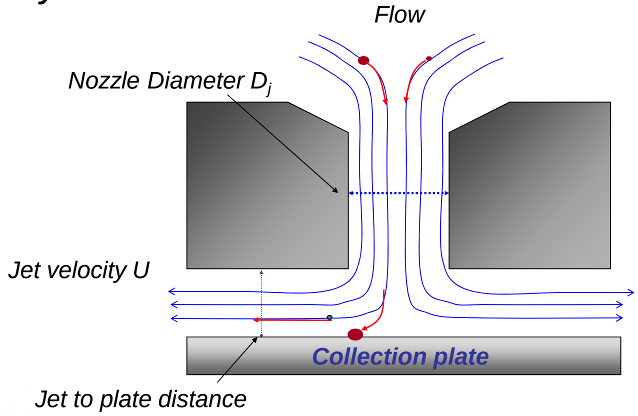
- DLPI+ and HT-DLPI+
  - 14 stages @ 10 lpm
- DGI
  - 5 stages @ 70 lpm



DEKATI

Impactor

- Aerodynamic diameter
- Gas velocity and dimensions different in different stages



ELPI+™ Samples from Santiago (City Center)

Collection time: ~4 days

Collection: Mass and Chemical Analysis

- Mass and chemical analysis of size classified particles
- D. Temesi et al: Size resolved chemical mass balance of aerosol particles over rural Hungary. Atmospheric Environment 35 (2001) 4347–4355

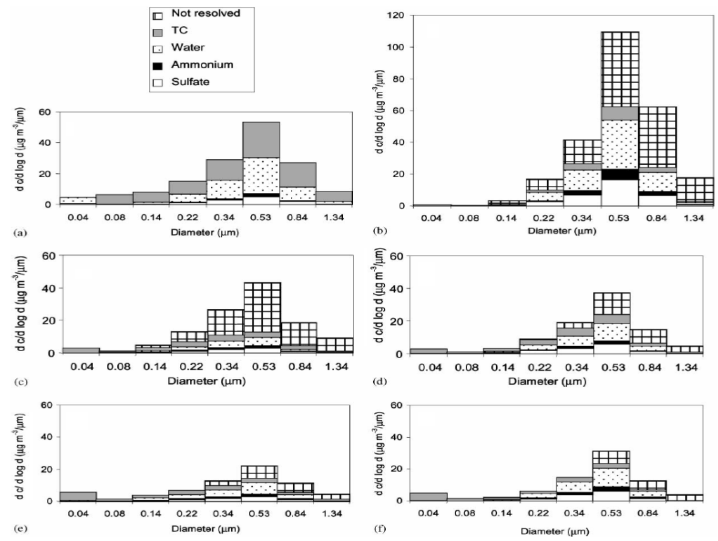
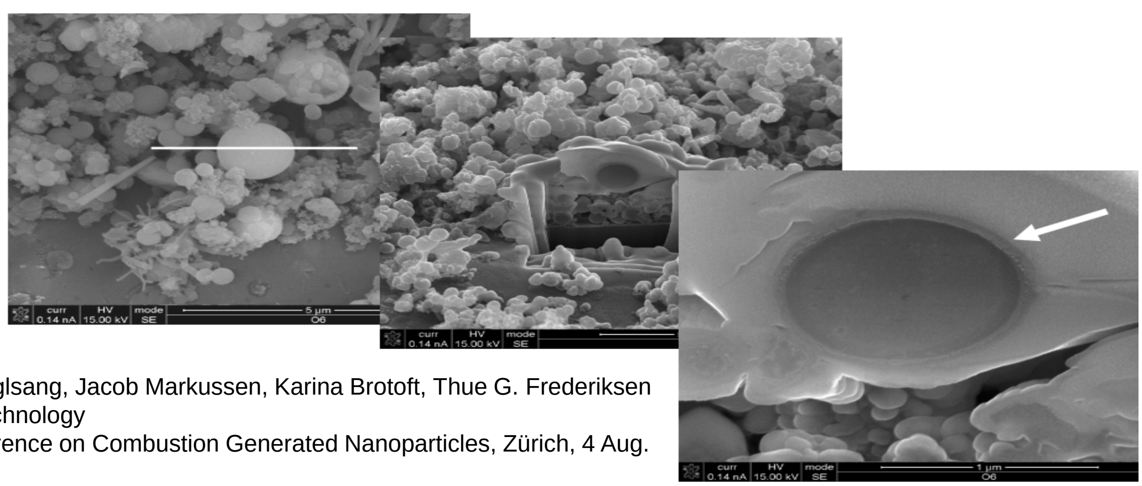


Fig. 3. Mass balances of different air masses. Air masses: east European (a), southwest European (b), northeast European (c), west European (d), northwest European (e) and local (f).

Collection: SEM and TEM



Karsten Fuglsang, Jacob Markussen, Karina Brotoft, Thue G. Frederiksen
FORCE Technology
ETH Conference on Combustion Generated Nanoparticles, Zürich, 4 Aug. 2010

DEKATI

ELPI+™

Electrical Low Pressure Impactor

DEKATI

ELPI+™: Electrical Low Pressure Impactor

- Number size distribution and concentration
  - Real-time, 10 Hz
- 6 nm - 10 µm
  - 14 size fractions
- Particles are collected
  - Enables subsequent chemical analysis on the collected samples
- Wide dynamic range
  - From outdoor air to power plant stack concentrations

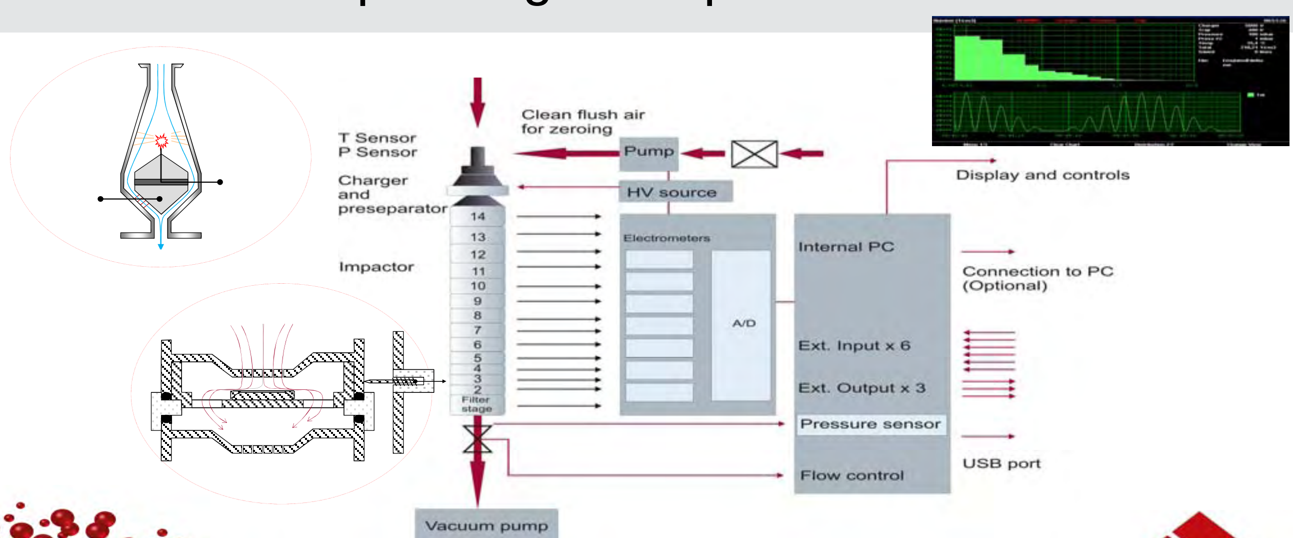
DEKATI

Jonna Kannosto

ELPI+™ Operating Principle

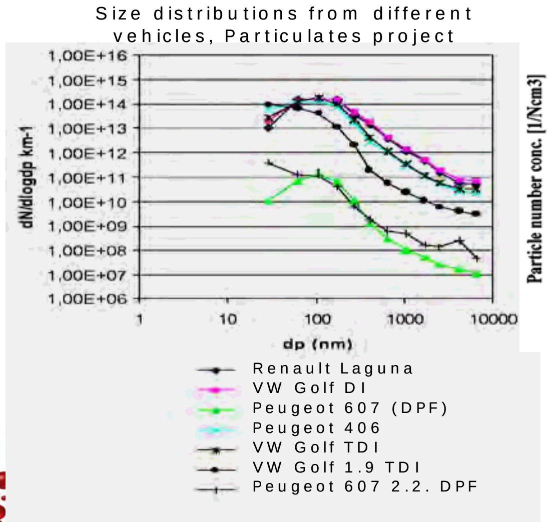
- Operation based on three main components:
  1. Impactor
     – Particle size fractionation
  2. Charger
     – Particle are charged before fractionating
  3. Electrometers
     – Current distribution - directly proportional to number distribution
     – Fast, sensitive

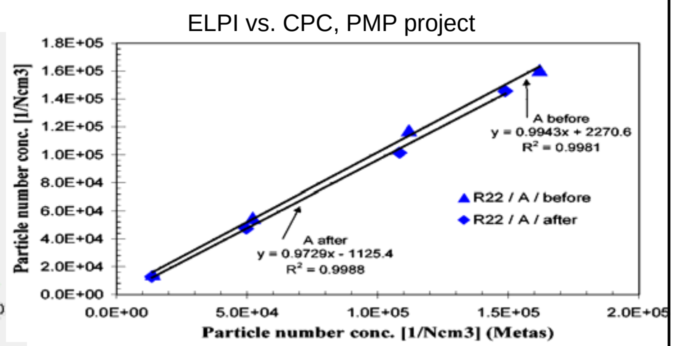
ELPI+™ Operating Principle



© Dekati Ltd.

Example data from ELPI+



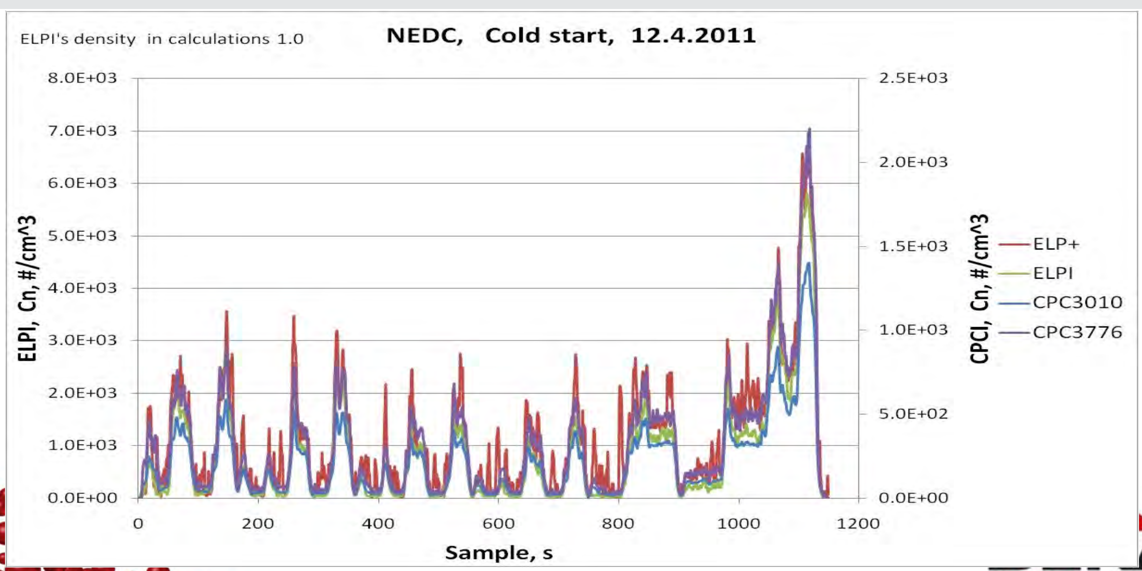


DEKATI

Göteborg 05.10.2004

199

ELPI+ number concentration measurement



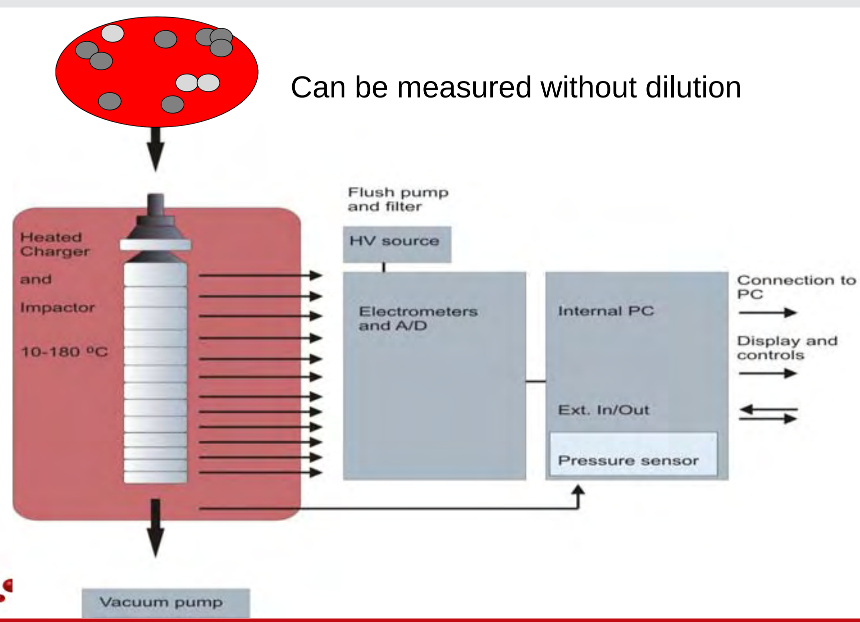
DEKATI

High Temperature ELPI+™

High Temperature ELPI+™

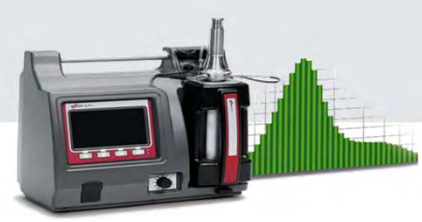
Hot Sample

Can be measured without dilution



Benefits of HT-ELPI+ in automotive exhaust measurement

- High sensitivity and no need for dilution
  - Measurement result comparable to PMP requirements
- The only instrument available for real-time size distribution measurement of exhaust particles at high temperature
- Easy application into on-board measurements – no need for a dilution system
- Directly applicable to blow-by measurements

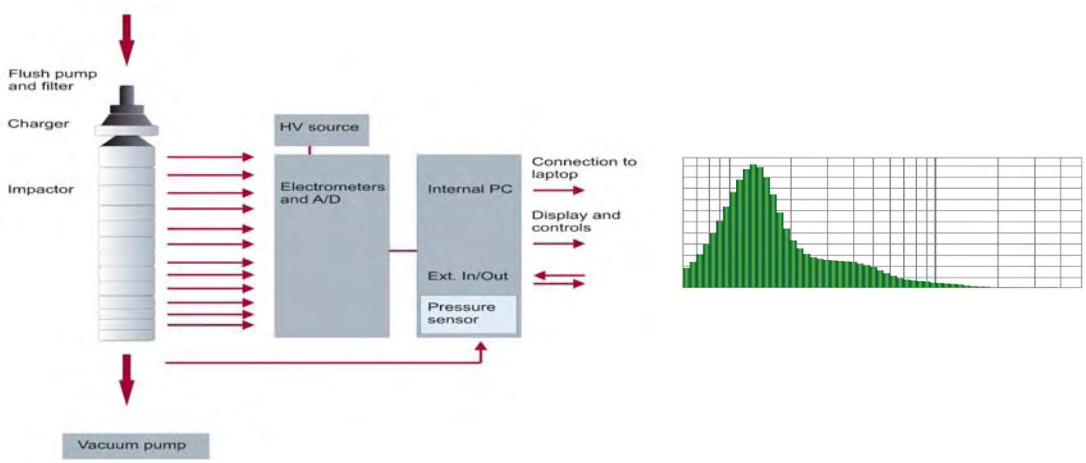


High Resolution ELPI+™

HR-ELPI+™ Operating Principle

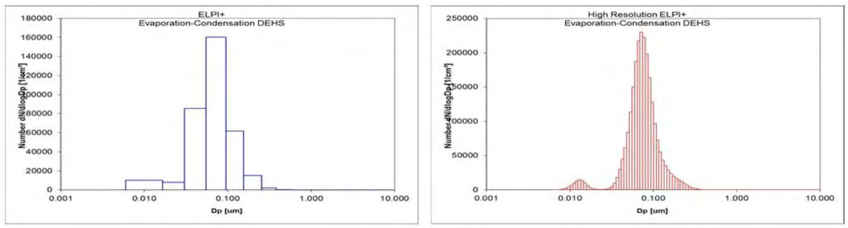
- Operation based on:
  1. Impactor
     – Particle size fractionation
  2. Charger
     – Particle are charged before fractionating
  3. Electrometers
     – Current distribution - directly proportional to number distribution
     – Fast, sensitive
  4. Data inversion in the HR-ELPI+VI™ software
     – Data inversion based on measured impactor kernel functions and iterative calculation routine

HR-ELPI+™ Operating Principle

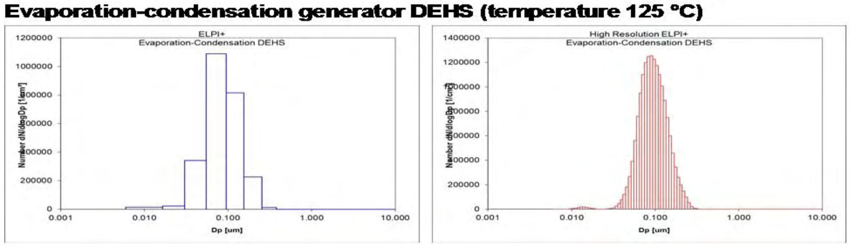


HR-ELPI+™ Data example: DEHS

Evaporation-condensation generator DEHS (95 °C)

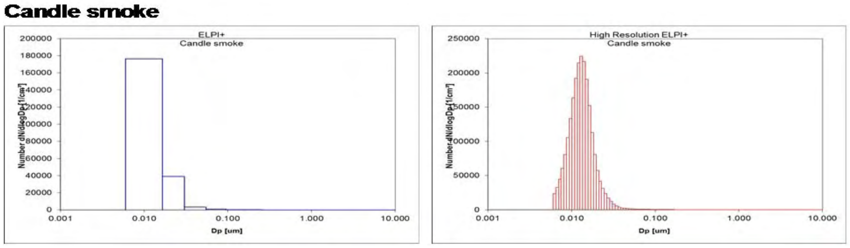


Evaporation-condensation generator DEHS (temperature 125 °C)

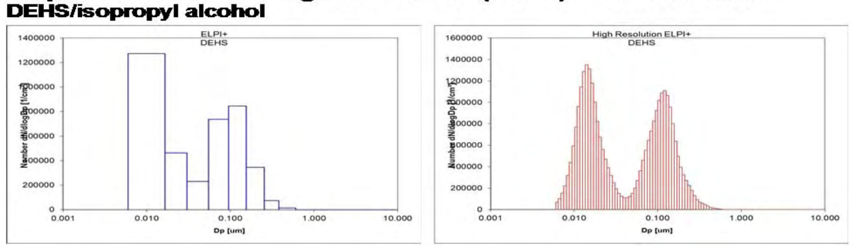


HR-ELPI+™ Data examples

Candle smoke



Evaporation-condensation generator DEHS (140 °C) + DeVilbiss 1:500 DEHS/isopropyl alcohol



HR-ELPI+™ Features

- 0.006 – 10 µm size range
- Number size distribution in either 100 or 500 size channels
  - 30/150 channels /decade
- Sampling rate 1Hz
- Sensitivity
  - 250 #/cm³ for 10 nm particles 20 #/cm³ for 100 nm particles 1.0 #/cm³ for 1 µm particles 0.1 #/cm³ for 5 µm particles

Benefits of the HR-ELPI+ in automotive exhaust measurements

- Wide size range real-time measurement of particles with a single measurement principle
- Applicable to exhaust particle, brake wear particle and blow-by particle studies
- Calculation of high resolution with no black box features
- Robust system even in difficult conditions

www.dekati.fi

DEKATI

Direct Reading Instruments for Diesel Particulate Matter

October 6, 2015 MDEC - Toronto

Scott Norman, CIH CSP
Product Specialist
TSI Incorporated
Shoreview MN

UNDERSTANDING, ACCELERATED

Overview

+ **Introduction to TSI**
+ **Motivation and Background**

+ **TSI Nanoparticle Emission Tester (NPET) Model 3795**
    - Principle of operation
    - Performance evaluation
    - Example measurements

+ **TSI DustTrak™ DRX Model 8533**
    - Principle of operation
    - Performance evaluation
    - Example measurements

Introduction to TSI Incorporated

+ Based in St. Paul MN, USA
+ Started in 1961 as **T**hermo-**S**ystems **I**nc.
+ Leader in particle measurement instrumentation for over 50 years

Particle instruments

+**Measure size and concentration of aerosol particles**
- Fundamental aerosol research
- Nanotechnology
- Filter testing
- Engine Emissions

Health & Safety instruments

+ **Measure aerosol mass for occupational exposure monitoring**

+ **Light scattering photometer**
  - Personal aerosol exposure levels
  - Area aerosol levels

+ **Ultrafine particle counting**
  - Respirator Fit Testing (PortaCount)

Diesel Particulate Matter

+ **Particulates**
  - Elemental carbon
  - Organic compounds
  - Sulfate
  - Nitrate

"Most diesel exhaust particles are tiny enough to be inhaled deep into the lungs where they pose significant health risk."

Workers Health and Safety Centre Federation of Ontario

+ **Gases**
  - Carbon monoxide
  - Carbon dioxide
  - Sulfur
  - Nitrogen oxides
  - Aldehydes
  - Benzene
  - Polyaromatic hydrocarbons

DPM background

+ Diesel Particulate Matter (DPM) is a recognized health concern for mine workers around the world.
+ Exposure limits are based on gravimetric mass measurement.
+ Direct-reading instruments are available to provide reliable DPM data in real-time.

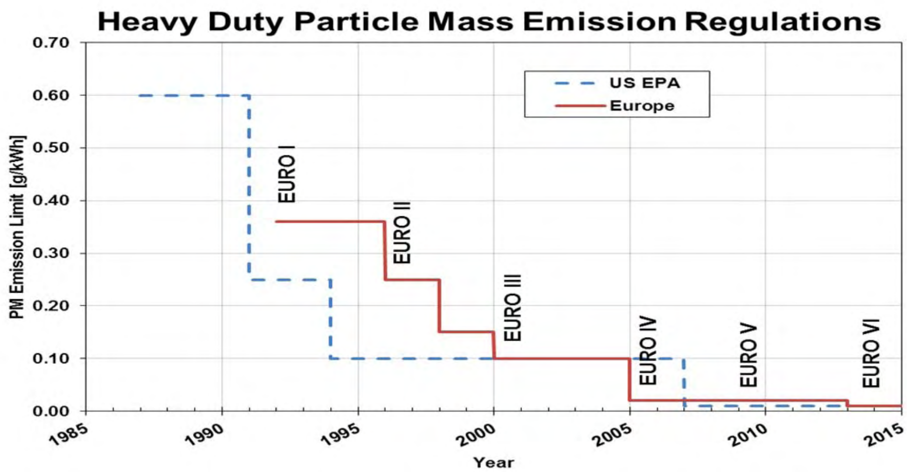
MSHA DPM Exposure Limits

Date	Limit mg/m3	Constituent	Interim / Final
2001	0.4	TC	Interim (not enforced)
2003	0.4	TC	Interim (enforced)
2006	0.308	EC	Interim
2007	0.350	TC	Interim
2008	0.160	TC	Final

TC = Total Carbon
EC = Elemental Carbon

Controlling Diesel Emissions in Underground Mining within an Evolving Regulatory Structure in Canada and the United States of America, S. McGinn, McGinn Integration Inc.

Reducing PM emitted by engines



+ **Very low PM at the emission limits is challenging to measure accurately**

Current particle number regulations in Europe

+ Europe started developing PN method in 2001 (PMP)

Table 1 European legislations that regulate particle number (PN) emissions

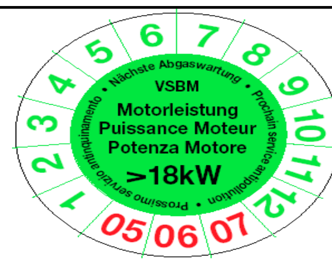
Vehicle category	Engine type	Standard	Introduction	PN limit
Passenger cars	Light-duty diesel	Euro 5b	2011	6×10^{11} P/km
		Euro 6a	2014	6×10^{11} P/km
	Gasoline direct injection	Euro 6b	2014	6×10^{12} P/km
		Euro 6c	2017	6×10^{11} P/km
Trucks and buses	Heavy-duty diesel	Euro VI (WHTC)	2013	6×10^{11} P/kWh
		Euro VI (WHSC)	2013	8×10^{11} P/kWh
Pending				
Off-road construction machinery	Heavy-duty diesel	SR 941.242	2015	1×10^{12} P/kWh (2.5×10^{5} P/cm^3)
Aircraft	Jet engine	(CAEP/10)	(2016)	TBD

Bischof, O. F., 2015, "Recent Developments in the Measurement of Low Particulate Emissions from Mobile Sources: A Review of Particle Number Legislations," *Emission Control Science and Technology*,

In-use DPF condition measurement

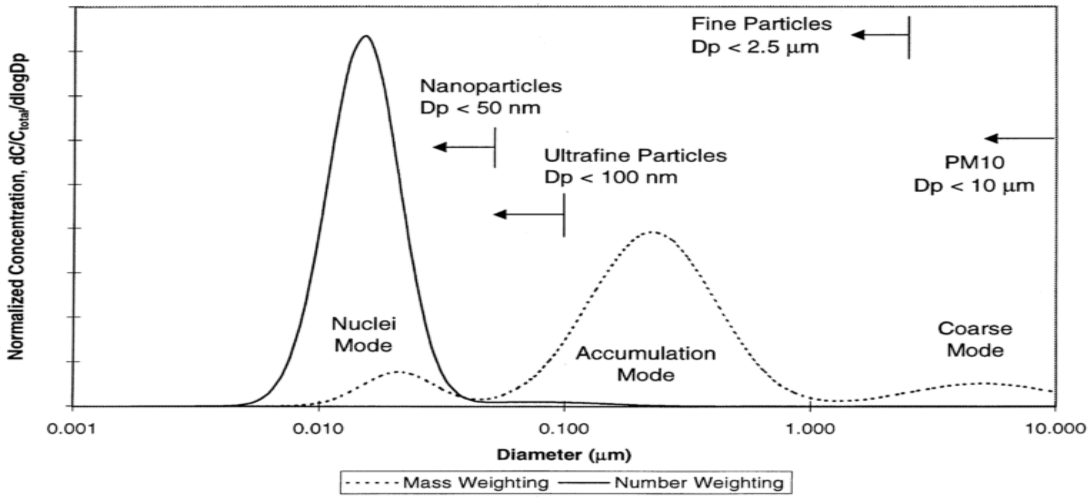
+ Diesel Particulate Filters (DPF) can fail in the field
  - Thermal shock
  - Uncontrolled regeneration
  - Canning defects
+ Problem:
  - Mass/opacity based systems not sensitive enough to measure downstream of DPF
+ Solution:
  - Measurement of ***solid*** particle number concentration
+ Swiss Regulation 941.242
  - Mandates biannual in-use testing of all non-road mobile machinery (NRMM)

Swiss Regulation 941.242



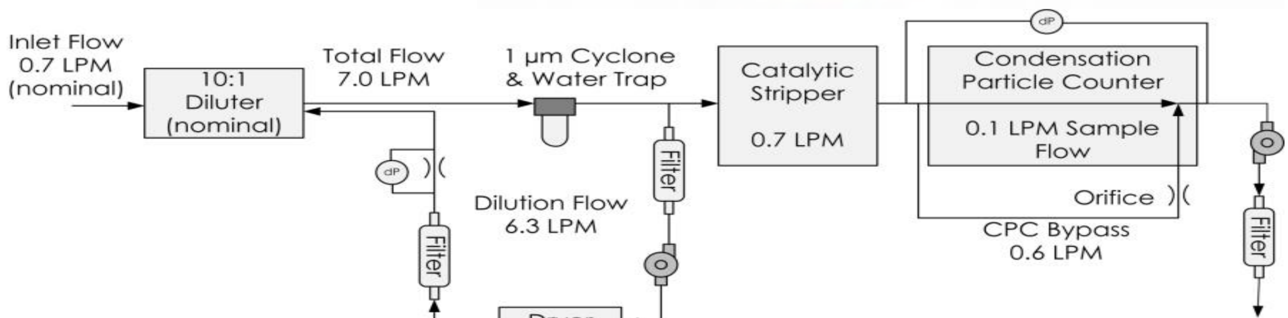
+ Requires bi-annual testing of NRMM used in Switzerland
+ Solid particle number concentration downstream of the DPF must be below 250,000 particles/cc
  - Measured at high-idle
  - 250,000 particles/cc limit meant to emulate existing standard. In reality emissions from a functioning filter are much lower.
+ Regulation promulgated January 1, 2015, enforcement begins April 1, 2017
+ TSI Model 3795 is first and only instrument certified by Swiss Federal Institute of Metrology (METAS) to test to this standard

Typical engine exhaust particle size distribution



Kittelson, Journal of Aerosol Science, 1998

Nano Particle Emission Tester (NPET) Model 3795



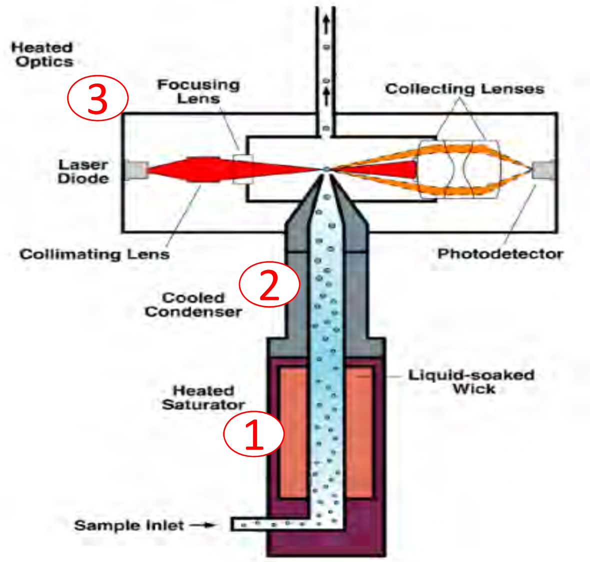
Condensation Particle Counter (CPC)

Three Basic Components

3. Optics
- Each particle passes through a laser, scattering light
- Each light scatter pulse is counted

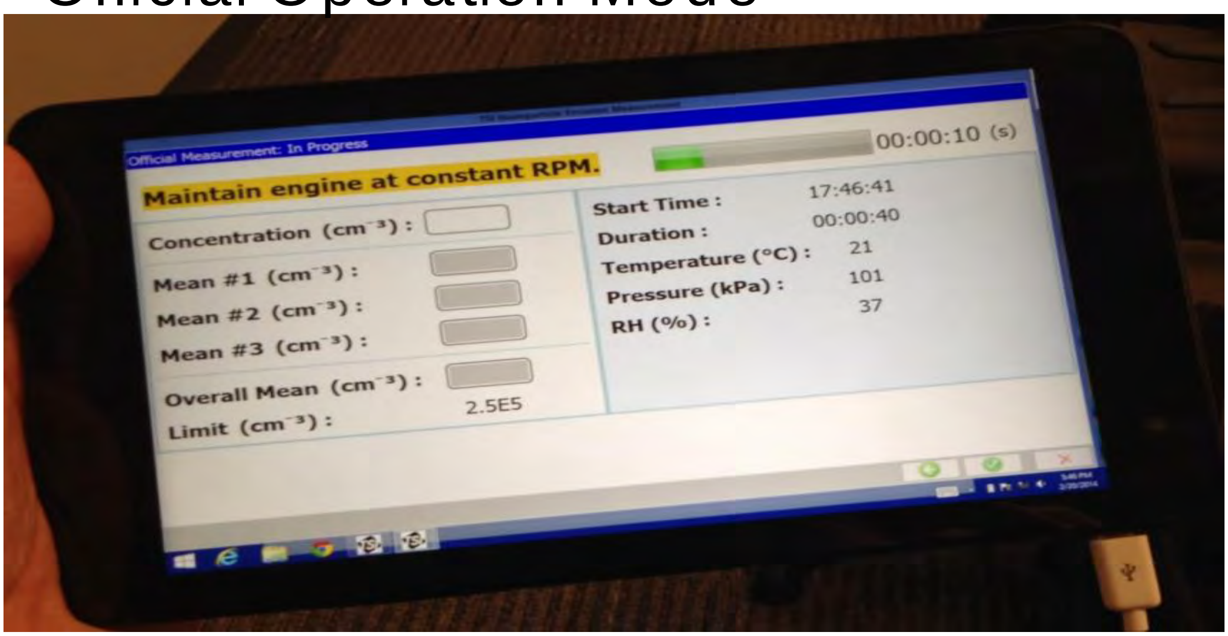
2. Condenser
- Cooled to cool particles
- Vapor condenses onto particles and they grow

1. Saturator
- Heated to saturate sample with isopropanol vapor



 7

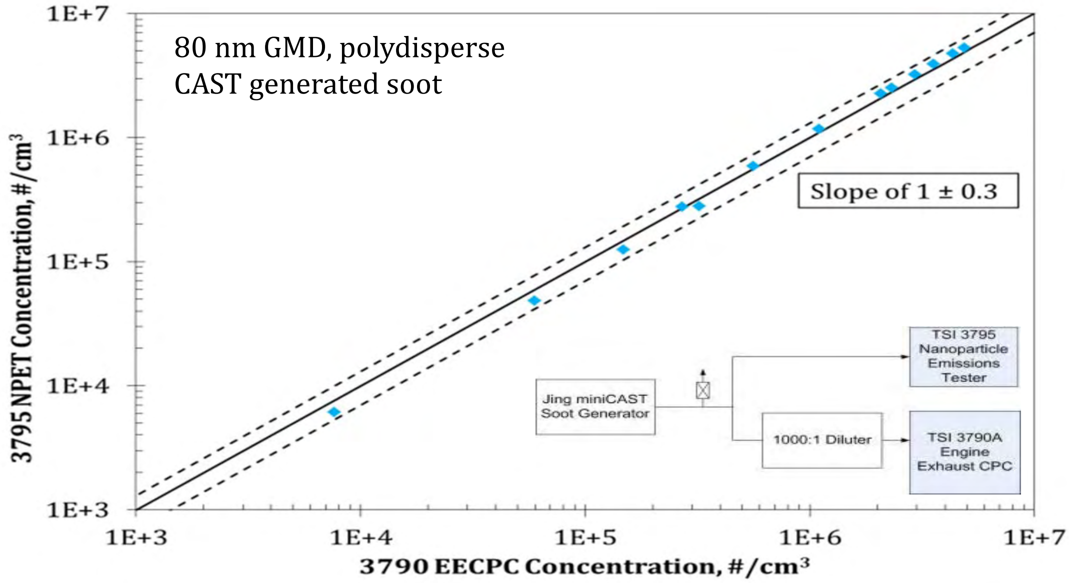
Official Operation Mode



 8

Concentration Linearity (log scale)

3795 NPET and 3790A EECPC



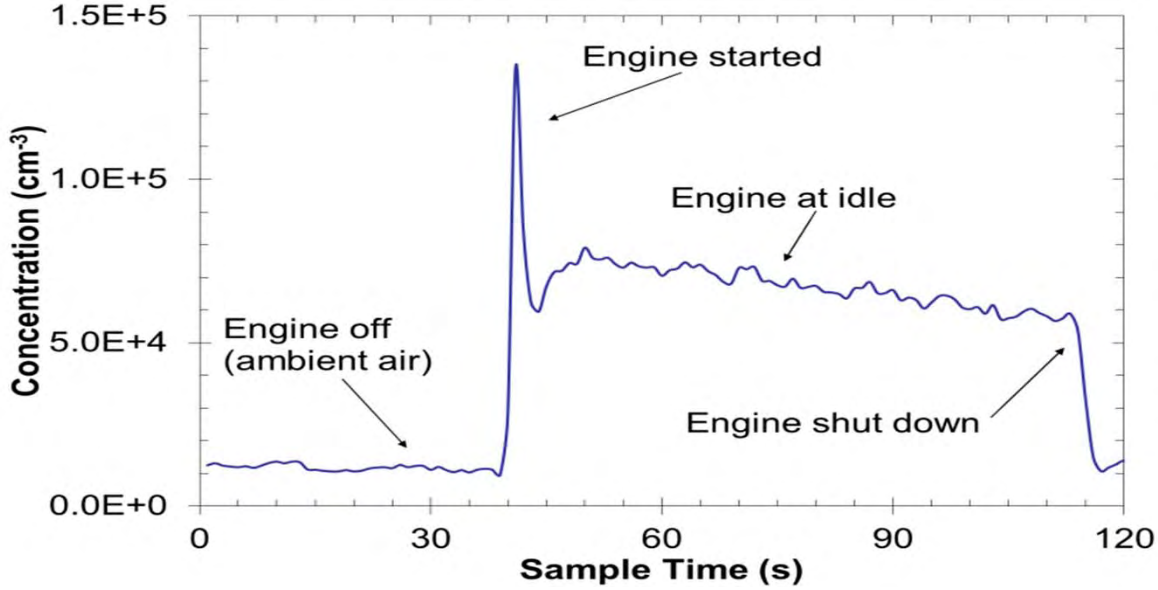
9

Example Application:

Bobcat Engine Startup (DPF Out)

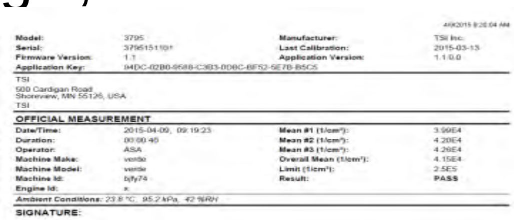
0

Example Application:
Bobcat Engine Startup (DPF Out)



1

Example Application:
Buses on route in Santiago, Chile



Model:	3795	Manufacturer:	TSI Inc.
Serial:	3795151101	Last Calibration:	2015-03-13
Firmware Version:	1.1	Application Version:	1.1.0.0
Application Key:	94DC-02B0-9588-C3B3-0D0C-BF52-5E7B-B5C5		

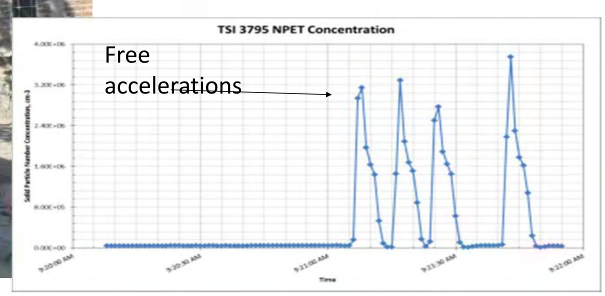
TSI
500 Cardigan Road
Shoreview, MN 55126, USA
TSI

OFFICIAL MEASUREMENT

Date/Time:	2015-04-09, 09:19:23	Mean #1 (1/cm³):	3.99E4
Duration:	00:00:45	Mean #2 (1/cm³):	4.20E4
Operator:	ASA	Mean #3 (1/cm³):	4.26E4
Machine Make:	verde	Overall Mean (1/cm³):	4.15E4
Machine Model:	verde	Limit (1/cm³):	2.5E5
Machine Id:	bjfy74	Result:	PASS
Engine Id:	x		

Ambient Conditions: 23.8 °C, 95.2 kPa, 42 %RH

SIGNATURE:



2

Summary of Santiago test results

	NPET Official measurement (at idle)					MAHA MDO 2 Opacimeter official measurement (free acceleration)		
Bus ID number	NPET measurement 1	NPET measurement 2	NPET measurement 3	NPET total measurement	Pass/Fail Limit=2.5E5 cm^{-3}	Opacimeter measurement 1	Opacimeter measurement 2	Pass/Fail Limit=0.24 m^{-1}
On route								
BDXR54	1.62E+04	1.75E+04	1.81E+04	1.72E+04	PASS	0.01	0.02	PASS
BJFB38	7.70E+03	7.49E+03	7.78E+03	7.66E+03	PASS	0.01	0.02	PASS
FLXD50	1.67E+06	1.71E+06	1.70E+06	1.69E+06	FAIL	0.07	0.07	PASS
BJFY74	3.99E+04	4.20E+04	4.26E+04	4.15E+04	PASS	0.01	0.02	PASS
BJFH22	4.75E+05	5.01E+05	5.04E+05	4.93E+05	FAIL	0.02	0.03	PASS
In SUBUS terminal								
CJRL33	7.21E+02	6.71E+02	5.83E+02	1.00E+03	PASS	N/A	N/A	N/A
CJRL49	4.00E+01	5.10E+01	6.50E+01	1.00E+03	PASS	N/A	N/A	N/A
CJRP81	2.95E+03	2.79E+03	2.87E+03	2.87E+03	PASS	N/A	N/A	N/A
CJRR35	9.13E+01	5.58E+01	5.08E+01	1.00E+03	PASS	N/A	N/A	N/A
CJRR38	4.66E+06	4.72E+06	4.57E+06	4.65E+06	FAIL	N/A	N/A	N/A

+ On road all five buses passed opacity test (<0.24m^{-1}) while only three passed Swiss test (<2.5E5 cm^{-3})
+ While bus BJFH22 failed Swiss test, opacity was consistent with the opacity from buses that pass NPET test
+ For same opacity measurement(2%), solid particle number measurement is 100x higher

DustTrak™ DRX Model 8533

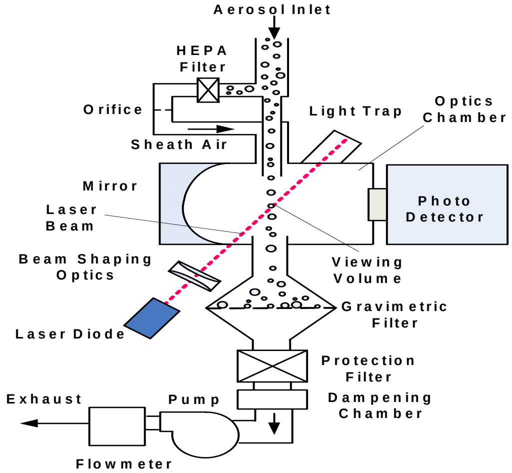
Light Scattering Photometer Technology

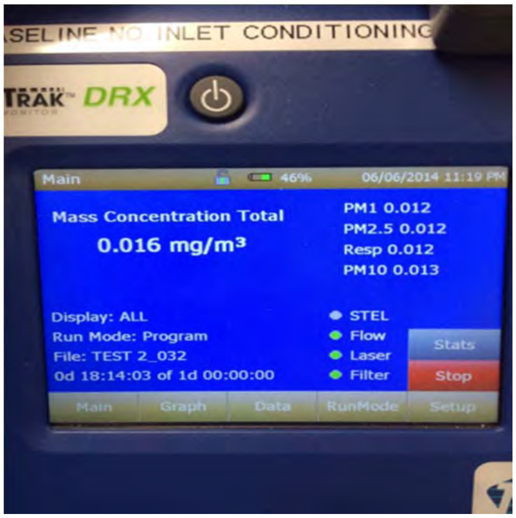
Portable, battery-operated industrial hygiene sampling instrument.

Can measure PM1, PM2.5, PM4, PM10 and Total Mass at the same time.

8533 DustTrak DRX

Light Scattering Photometer Technology





Particle counting vs. light scattering

Particle counting is like counting the number of rain drops or snow flakes that hits the window

OPCs count the number of raindrops (or snow flakes) hitting the windshield.

- Works for certain size drops at low concentration levels

CPCs count the number of ultrafine particles

6

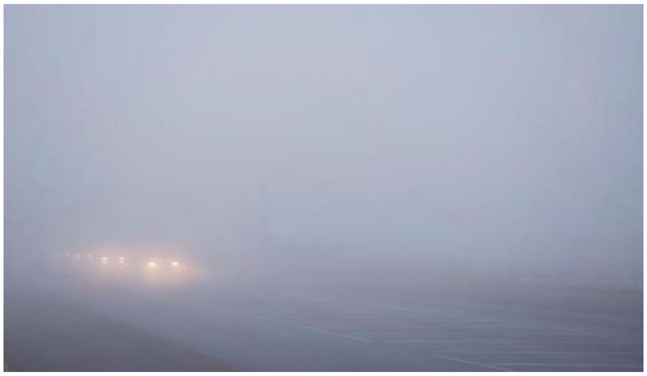
Photometric light scattering

Photometers measure the amount of light scattered by the fog.

Think of how bright the fog is in the headlights.

“thicker fog” is brighter.

A photometer would calculate more mass based on a brighter response from thicker fog based on the calibration aerosol.



7

Calibration aerosol

Photometers are calibrated to a known test aerosol.

- known density
- known refractive index
- known size distribution

A bucket of golf balls will not weigh the same as a bucket of ping pong balls.

The photometer sees Ping Pong balls, but calculates mass concentration based on the calibration aerosol (golf balls)

8

Calibration factor

Calibration factors are developed to 'inform' the instrument that the sampled aerosol is different than the test aerosol. Thus the mass measurement needs correction.

Density
Size
Refractive index

9

DustTrak DPM Correction Factor

University of Utah Study

+ Compare DustTrak 8020 to NIOSH 5040 sampling results for DPM.

+ 7 trips to underground hard rock mines in Utah and 3 trips in Montana

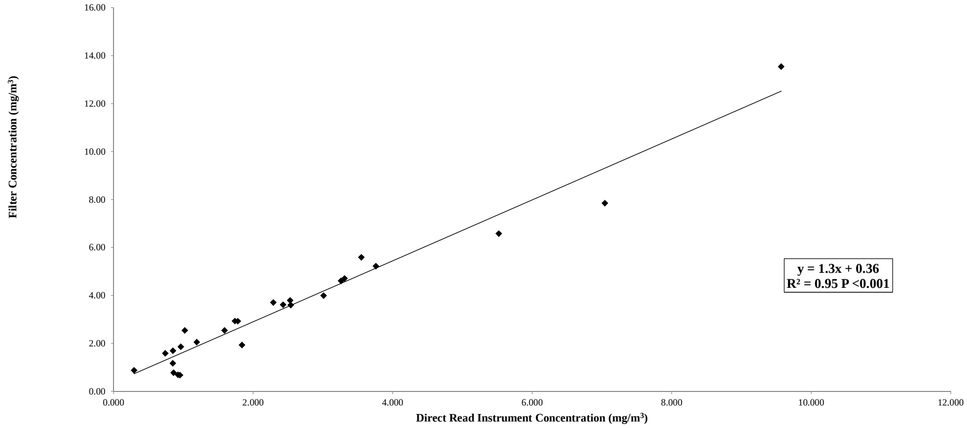
Gravimetric ug/m3	DustTrak ug/m3	K factor
170	245.9	0.691
208.1	214.6	0.970
311.4	363.2	0.857
263.9	438.3	0.602
1214.4	2220.6	0.547
353.6	508.8	0.695
115.1	336.7	0.342
23.8	57.3	0.415
19.8	71.4	0.277
46.7	80.8	0.578

AVG K factor **0.597**

K factor = gravimetric / DustTrak

0

DustTrak DPM Correction Factor
University of Utah Study



DustTrak concentration readings are highly correlated to filter concentration measurements.

1

DustTrak DPM Correction Factor
Customer data

Gravimetric ug/m3	DustTrak ug/m3	K factor
49	152	0.322
82	362	0.227
52	82	0.634
100	126	0.794
80	176	0.455

Avg K factor **0.486**

2

DustTrak K Factors

	Photometric Calibration Factor
Factory Calibration	1.0
Respirable Silica (1)	0.712
Wood Smoke (4)	0.64
DPM (1)	0.597
DPM(2)	0.486
Outdoor Ambient Urban Pollution (3)	0.38

(1) University of Utah – Rodney R. Larson, et al.
(2) TSI Metal Mining Customer, 2014
(3) Wallace , et. al, Journal of Exposure Science and Environmental Epidemiology, 2011.
(4) McNamara, et al, Aerosol and Air Quality Research, 11:315-322, 2011.

Strengths and limitations of photometers

Limitations

Calibrated to test aerosol
Humidity effects
Contaminated optics

8533 DustTrak DRX Desk top

Strengths and limitations of photometers

Strengths

Real-time
Data logging
Alarms

8534 DustTrak DRX Handheld

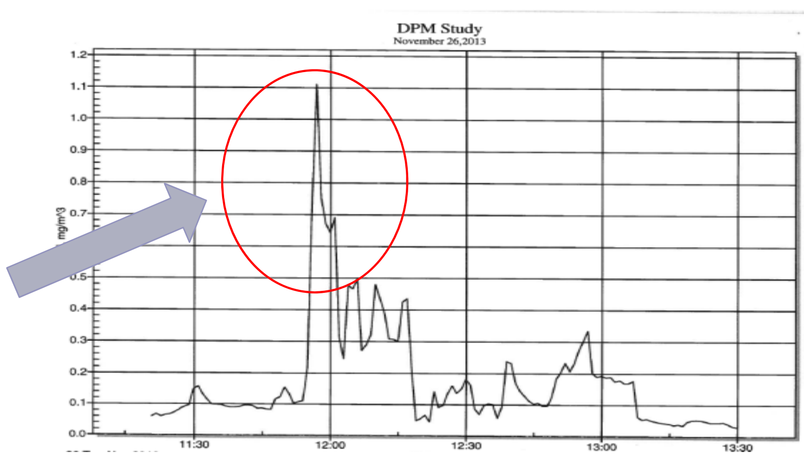
Logged Data

Customer data

Avg = 0.176 mg/m^3

Max = 1.11 mg/m^3

What caused this spike?



Application examples
Personal monitoring

Mining

Organization has characterized site aerosol exposures and developed custom calibration factors for silica.

Miners wear AM510 personal aerosol monitors on a regular basis to track silica exposure levels.

Perimeter monitoring

- Track wind, weather and aerosol concentration
- Logging data for community awareness
- Action level for dust suppression activities

Summary DustTrak DRX 8533

+ Precise
+ Portable
+ Direct Reading
+ Data Logging

+ Measurement of aerosol mass concentration.

Desktop DustTrak DRX Aerosol Monitor
Measuring welding shop exposures

 9

NPET 3795 Summary

+ NPET can determine DPF condition at idle by measuring solid particle number concentration
+ Certified to test to SR 941.242
+ Good agreement with established technology
+ Designed for portability, enabling quick and easy field measurements

 0

Q & A

Scott Norman, CIH, CSP
Product Specialist

TSI Incorporated
Shoreview, MN
(651) 490-2702
scott.norman@tsi.com