INCO/DEEP DIESEL PARTICULATE TRAP PROJECT

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Introduction

- Project Background – a quick review
- Project Status – experience to date
- Exhaust over-heating?
- Conclusions to date
- Path forward
- Acknowledgments

Project Background – a quick review

Health Effect and Regulations

- The suspected adverse health effect of diesel emissions have received increasing attention over the last 'several decades'
- ACGIH progressively reduced its TLV for diesel exhaust from 0.15 to 0.05 then 0.02 mg/m3 over the last 6 years
- The current Ontario standard is 1.5 mg/m3 measured as RCD
- Typical average level of RCD at Inco ranges from 0.1 – 0.5 mg/m3
- Inco trap field test has the nominal DPM emission target of 0.05 mg/m3, EC

The Challenge

- The changes in TLV amount to at least one order of magnitude reduction in DPM
- It would be technically an impossible task to achieve this reduction, by increasing the ventilation rate
- The only effective, practical and commercially available DPM reduction strategy for EC, appears to be diesel particulate filter system

Diesel Particulate Filter Technology

- The only effective, practical and commercially available DPM reduction strategy for EC, appears to be diesel particulate filter systems (for 0.02 to 0.05 mg EC DPM/m3)
- Particulate trap filters have been available since the mid – 80's, however the experience in mining has been mixed due to problems with regeneration, maintenance, and reliability issues.
- Successful usage has been demonstrated at:
  - South Western German Salt mine, has been using diesel particulate filter traps since early 90's with sulfur content of fuel < 0.05 %; and
  - Saskatchewan Potash mine has used traps for the last several years apparently without significant operational or maintenance problems
  - …Swedish mines too…
- Recent extended tests at BMS mine were also very encouraging.

DPF Selection Process/Methodology

4 days duration technical workshop program was launched at Inco in Nov. 2000, at which sessions (presentations, discussions, etc.) were held with

- Various European and North American trap engine manufacturers and fuel additive companies
- DEEP technical members, NIOSH scientists
- Mine personnel, USWA members
- DEEP primary technical consultant

Input and important discussions were held with 3 offshore underground mining operations in Sweden and Germany, as well a visit to two underground mine sites in Germany to acquire,'first hand' knowledge of trap's system, and associated operational challenges

Trap Selection Criteria

- Greater than 90% reduction (filtration rate) in elemental carbon – mass
- Effective filter lifetime (> 2000 hrs until ash removal and > 6000 hrs until filter replacement)
- Filter system must be reliable, robust and easy to maintain
- No increase of any other toxic emissions, (or secondary emissions)
- No damage to engine
- No increase in fire risk
- VERT certified, or in process of approval

Let us remember, that the most important aspect is the long term robustness of the system, reasonable operating maintenance, cost, and operational acceptance

Trap's used for the Inco project

	Vehicle	Supplier	EC redn	Hrs	Regeneration
1.	Deutz Scoop	JMC – Germany	99.9%	1,165	on-board in-use +add
2.	DDEC Scoop	ECS/Unikat/Comb	92 - 95%	791	on-board plug-in
3.	DDEC Scoop	Engelhard	99.9%	2,221	passive catalysed
4.	Kubota Tractor	ECS/3M Omega	91%	430	plug-in on-board
		ECS/ Combifilter	99.9%	146	on-board plug-in
5.	Kubota Tractor	DCL Titan	99.9%	338	off-board electrical
6.	Deutz Truck	not available			

NOTES:

a) VERT certifications at one level or another have been issued for filters or systems (except Englehard)

b) Silicon carbide filters are used in the ECS/Unicat & DCL Titan systems (others cordierite or fibre)

c) Elemental Carbon reductions (EC redn) – NIOSH 5040 are similar results to the PAS 2000 EC surface area reductions

Project Status

…experience to date…

Kubota Tractor

ECS/3M/Omega Filter System Onboard Electrical Regeneration

- Test conducted by NIOSH found the filter to be 91% efficient on soot removal

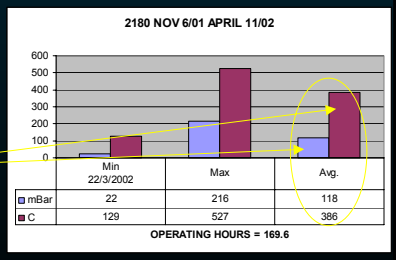
•Probes in place for
•efficiency testing

Kubota Tractor

ECS/3M/Omega Filter System Onboard Electrical Regeneration

- Data logger mounted next to the operators compartment monitors temperature, backpressure and rpm

- The average back-pressure, and temperature of 5 months operation is 118 mbar and 386 deg. respectfully



Kubota Tractor

ECS/3M/Omega Filter System Onboard Electrical Regeneration

- Total hours on the DPF 430
- Typically the unit is to be regenerated at the end of the shift

Kubota Tractor

ECS/3M/Omega Filter System Onboard Electrical Regeneration

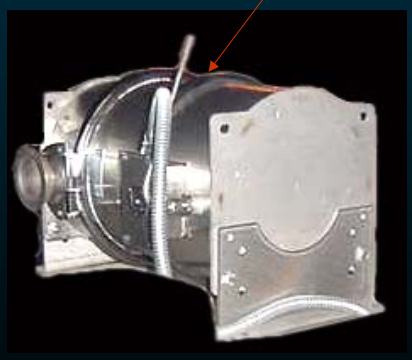
- Outside of some small operational issues (blown fuse in regeneration panel, not plugging in for regeneration (at the end of each shift) the DPF functioned reasonably well
- The bad news is that 3M fiber-wound diesel particulate filter is no longer available on the market.
- As a result ECS replaced it on cost sharing basis by Combifilter

Kubota Tractor

ECS/Unikat/Combifilter On Board Electric Regeneration (Replacement for ECS/3M/Omega)

- Combifilter installed in May 10/02 upon arrival from Sweden
- Requires regeneration station
- No catalyst in the system, no reduction of CO, or HC

•ECS/Unikat/Combifilter



Kubota Tractor

ECS/Unikat/Combifilter On Board Electric Regeneration Replacement for ECS/3M/Omega

- Total hours on the DPF, 146
- Test conducted by NIOSH in June, 2002 found the DPF to be 99.9 % efficient
- The unit is to be regenerated at the end of the shift

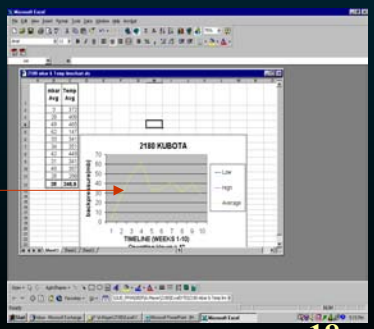
Kubota Tractor

ECS/Unikat/Combifilter On Board Electric Regeneration Replacement for ECS/3M/Omega

- Still some operational issues, not plugging in for regeneration at the end of each shift the DPF is functioning well
- The model S5 is regenerated over 50 - 60 minutes when the vehicle is not in operation
- This tractor is a personnel transportation vehicle with low utilization

ECS/Unikat/Combifilter On Board Electric Regeneration (Replacement for ECS/3M/Omega)

- Data logger mounted next to the operator's compartment monitors, temperature, backpressure and rpm
- The average weekly back-pressure, and temperature of 10 weeks of operation is within the range of 30 - 60 mbar, and 150 - 470 C

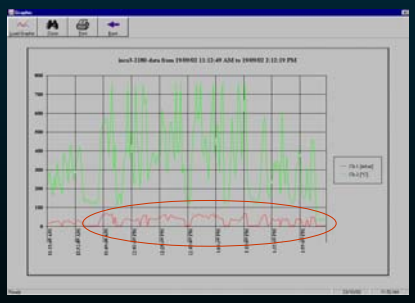


Kubota Tractor

ECS/Unikat/Combifilter - On Board Electric Regeneration (Replacement for ECS/3M/Omega)

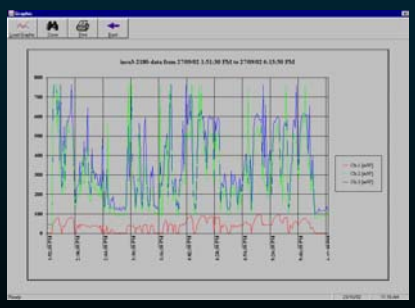
Typical backpressure & temperature trend, Sept. 23 - 27/02

operating hours =11



Typical backpressure & temperature trend, Sept. 27 - Oct. 3/02

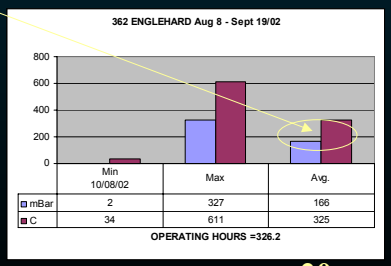
operating hours = 4



DDEC Scooptram

Engelhard Passive Catalyzed System

- There is presently over 2221 hours on this system with no operational difficulties **
- The average back-pressure, and temp. for two month (Aug - Sept/02) period amounts to 166 mbar, and 326 deg. C
- The maximum back-pressure, and temperature for the same period reaches 327 mbar, and 611 deg. C
- ** A fire incident occurred recently and trap system was de-installed



DDEC Scooptram
Engelhard Passive Catalysed System

- The efficiency of the Engelhard DPF system (measured by NIOSH in June, 2002 shows 99.9% filtration on soot removal
- The test taken by AVL in the exhaust port of the scoop recorded a value of 0.0% - 0.2% opacity
- The ambient air opacity resulted in 0.0% readings

•AVL - Opacity meter

DDEC Scooptram
Engelhard Passive Catalyzed System

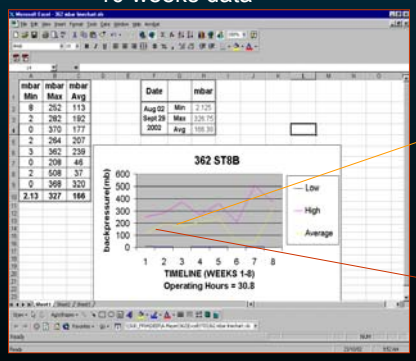
Concluding Remarks

- Fully passive catalytically coated filter can be an excellent low-complexity and cost effective solution for production scoop
- The filter survived an accident when mud penetrated into the cells from below (the discharge side) - proof of robustness
- Backpressure remains quite high 150 - 250 mbar reaching sometimes 300 mbar for extended periods - This remains to be analyzed in detail
- Measurable increase in NO_2 was observed
- Filter had to be cleaned from ash at least 3 times. This appears to be to often before reaching 2200 hours

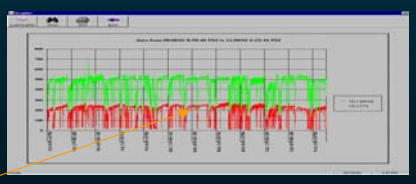
DDEC Scooptram
Engelhard Passive Catalyzed Filter

Weekly average backpressure

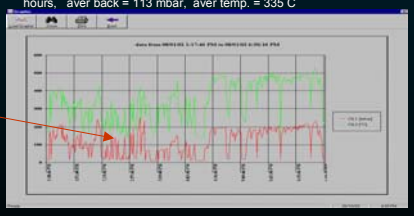
10 weeks data



Aug. 8 - 17/02 backpressure & temperature trend, 73.5 operating hours, aver back = 192 mbar, aver temp = 456 C



Aug. 1 - 8/02 backpressure & temperature trend, 6.3 operating hours, aver back = 113 mbar, aver temp. = 335 C



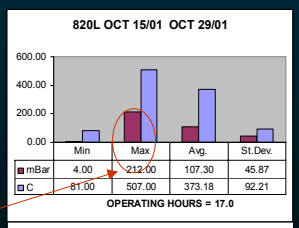
Deutz ST8 Scoop
JMC On Board Fuel Additive Dosing & Electric Regeneration System

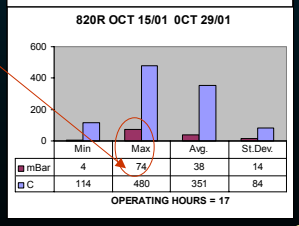
- Total accumulated hours on trap is over 1165
- Since Deutz engine has a dual exhaust system, two sets of filters are installed
- These heater elements allow for onboard regeneration

Deutz ST8 Scoop

JMC On Board Fuel Additive Dosing & Electric Regeneration System

- The Deutz engine left bank had "smoking" problem, burning oil – (about 300 hours of DPF installation)
- This resulted in difficulty with regeneration and much higher backpressure on the left bank
- Subsequently the engine had to be changed

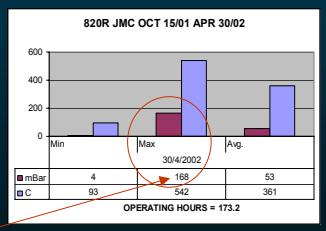


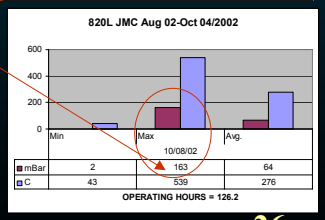


Deutz ST8 Scoop

JMC On Board Fuel Additive Dosing & Electrical Regeneration System

After the engine change the filter system shows equal readings side to side in the range of 168 mbr maximum





Deutz ST8 Scoop

JMC On Board Fuel Additive Dosing & Electric Regeneration System

- Intake side of the filter. Note the soot trapped in the ceramic channels of the filter

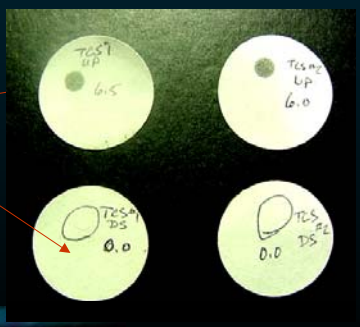
- Discharge side of the JMC silicon carbide filter. No visible soot can be seen

Deutz ST8 Scoop

JMC Electric On-Board Fuel Additive & Electric Regeneration System

- The trap efficiency test conducted by NIOSH, June, 2002 shows 99.9% soot reduction

- The ECOM-AC "smoke" readings averaged 6.5 upstream with a white filter downstream of the trap - no pollutant was detectable on the filters



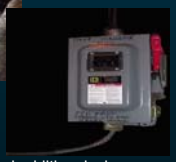
Deutz ST 8 Scoop

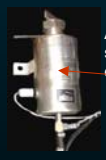
JMC On Board Fuel Additive & Electric Regeneration System

- **Concluding Remarks**

- **The Scoop on which this trap is installed is not a production unit. The duty cycle can vary a lot from high load to relatively light loads over extended periods**
- **The selected system of passive (by fuel additive RHODIA Ecolys Cerium Oxide) and active back-up provides the chance that plug-in active regeneration might not be necessary for a 'long time' -**
- **-Certainly, not on a regular shift to shift basis, since the additive can cope with short light loads period quite well**
- **This is a robust system, but operational acceptability and complexity of regeneration equipment remains an issue**
- **Filter had to be cleaned twice from ash.**

JMC computerized fuel additive dosing & electric regeneration system





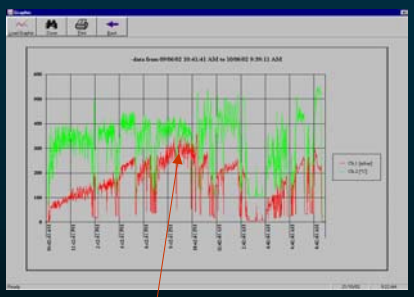
Automatic fuel additive dosing system. Fuel additive is added only during regular maintenance

A build –up of soot will result in the lights on the monitor gradually signalling from left to right. This monitor gauge is installed on the dash allowing the operator to view the build up of particulate in the filter unit

Deutz ST 8 Scoop

JMC On Board Fuel Additive Dosing & Electrical Regeneration System

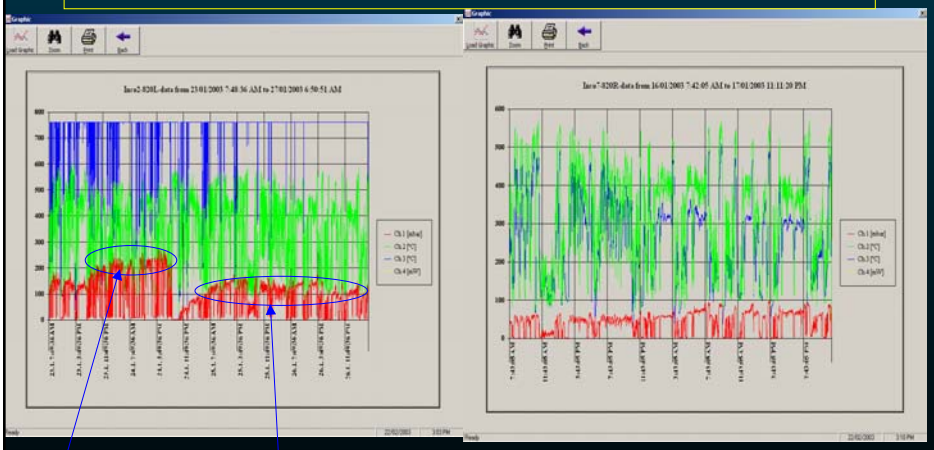
Typical back-pressure & temp. trend, (30 hours operation)



Abnormal back-pressure trend, (25 hours operation) in the range of up to +300 mbar

Deutz St 8 Scoop – Total hours = 1100

JMC On Board Fuel Additive Dosing & Electric Regeneration System



Engine Left Bank

Engine Right Bank

High back-pressure prior trap to cleaning

Back-pressure range after trap cleaning during 40 hours operation on fuel additive – no electrical regeneration requires

Kubota Tractor

DCL Titan Off-Board Electric Regeneration

- The system was installed Feb/02 and comprises two interchangeable filters
- The "loaded" filters with soot are removed from the vehicle and placed on the off - board regeneration station
- The regeneration station provides automatic control of combustion

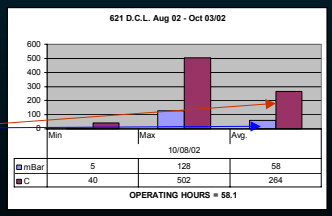
•Quick Release Clamps

•Regeneration "Cooker"

Kubota Tractor

DCL Titan Off-Board Electric Regeneration

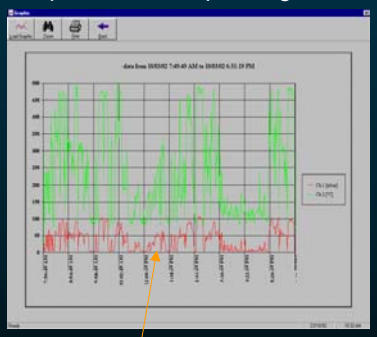
- The system has accumulated 338 hours
- Test conducted by NIOSH, May/02 indicates 99.9 % filter efficiency
- The challenge may be associated with daily replacement of filter
- The average engine back-pressure since installation is 58 mbar, and the temperature is below 300 deg. C



Kubota Tractor

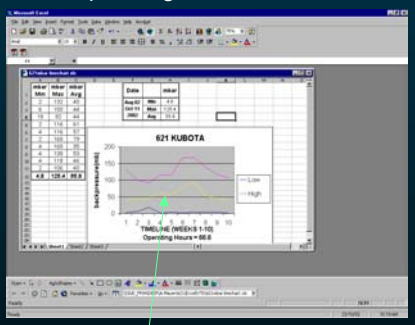
DCL Titan Off Board Electric Regeneration System

Typical weekly back-pressure & temp. trend - 7.8 operating hours



Average back-pressure and temperature =57 mbar and 270 C

10 weeks data of back-press trend - 66.6 operating hours



Weekly average range = 40 - 90 mbar, and 190 - 300 C

DDEC Scoop

ECS/Unikat Dual S18 Combifilter

- The installation of the Combifilter were completed in Mar/02
- The system consists of dual filter assembly vertically mounted & on board electrical regeneration

•Dual Filter assembly

DDEC Scoop

ECS/Unikat Dual S18 Combifilter

- The Swedish made Regeneration Control Panel, etc was not CSA approved
- Subsequently the Control Panel was, upgraded, CSA approved and re-installed 06May02

DDEC Scoop

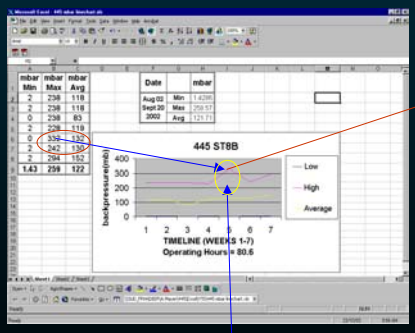
ECS/Unikat Dual S18 Combifilter

- The system has accumulated some 873 hours
- During a regular P.M. while carrying out ECOM test it was determined that the filter had failed as the readings (Bacharach number) up stream and down stream were equal.
- Failure was due to operating the unit without regeneration
- The investigation is ongoing at this time

DDEC Scoop

ECS/Unikat Dual Combifilter

Weekly average back-pressure
7 weeks data



Back-pressure build up in week due to lack of regeneration

Back-pressure & temp. trend, 73 operating hours

No regeneration

Trap system regenerated

DDEC Scoop
ECS/Unikat Dual Combifilter

- **Concluding remarks**

- Concept - An active non-catalyzed filter large enough to collect soot over 2 working shifts, followed by on board electric regeneration

- Robust system and no secondary emissions

- The single biggest challenge is the operators acceptance - It is a ‘difficult’/ not a normal task for operators to carry out the requirement of routine regeneration (45 - 60 min.) at the end of each shift - “ TO PLUG IT IN”

Emission Testing

- The diesel units filters are tested on a regular basis using an ECOM - AC unit

- This emission testing system directly reads oxygen, CO, NO2, NO, and hydrocarbons (%CxHx) in the exhaust

•ECOM emission tester with tailpipe probe
•being held in front

Emission Testing

- **In addition, the ECOM 'takes' a smoke reading.**
- **The 'density of soot' on a piece of paper is compared to a known value and determines the smoke number, (called Bosch smoke test)**

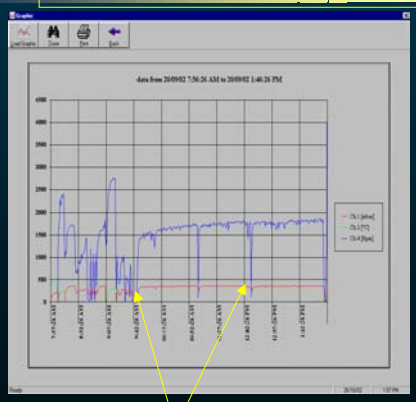
•The two filter papers show the result of ECOM Bosch smoke test before and after the filter.

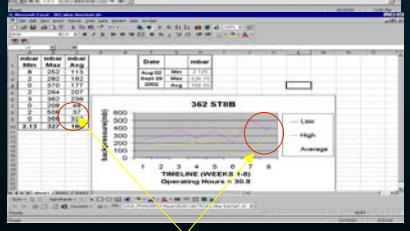
•The spots on the filter paper are then compared with the smoke chart in the upper half of the picture

Exhaust over-heating

- **DPFs** can become plugged and give rise to excessive back-pressures, and temperatures,
- **Two unexpected incidents at INCO**
  - Fire on the DDEC Scoop with Englehard passive filter – oil sprayed from failed turbocharger
  - Unikat/Combifilter trap system failed due to scheduled regeneration not being performed

Fire Incident on DDEC Scoop, Engelhard DPF, Total hours = 2221

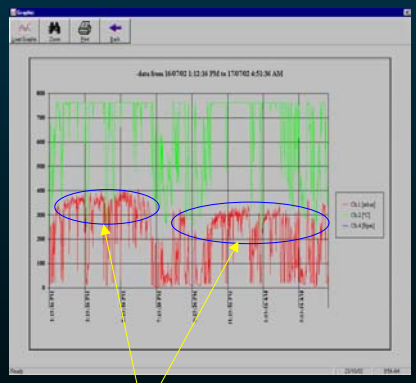


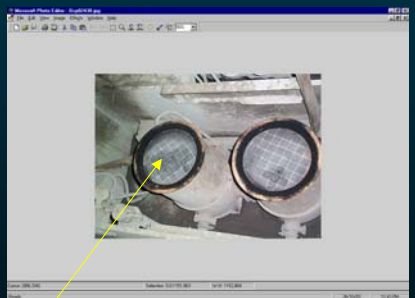


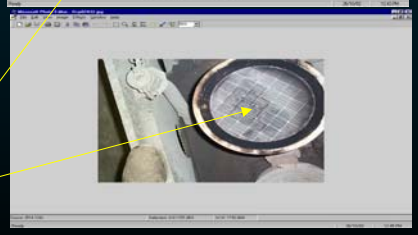
Back pressure trend prior to fire incident, the week of Sept 23, 2002 31 operating hours

Weekly aver & max back-pressure trend prior to fire – the week of Sept 23, 2002

Failure of Combifilter on DDEC Scoop Total hours = 873







Failure to carry out thr routine regeneration (plug in) at the end of each shift lead to the filter failure

Conclusions to date

- Operator acceptance is encouraging – even though there is a reluctance to lose any time for trap systems (…or anything else…)
- The systems are all very effective at reducing DPM in properly operating engines
- The operating and maintenance costs seem to be within the acceptable range. Regeneration at the end of the shift at a plug-in station is workable for the light duty vehicles! For heavy-duty ??….?
- To date premature break-down of a filter media due to not performing the required regeneration
- There may be problems with catalyzed filters – as NO2 levels can increase
- ? Oversizing the traps would have a triple benefit – better capture efficiency, more "capacity" for soot accumulation for longer operation, and lower backpressures ?

What is INCO doing with the results of this projects?

Equip 14 units of mobile equipment with DPF system

Engine warranties when vehicles are equipped with the DPF

Things to look out for

Strong on road market growth for DPF will provide attractive opportunities regarding better availability and costs for users

INCO DPF Specifications

These are adapted from the VERT specifications by Team of Inco/DEEP members, Drs Schnakenberg and Bugarski of NIOSH, and Andreas Mayer, Inco/DEEP Primary Technical Consultant

- **Efficiency** - 95% removal, both for particulate numbers and elemental carbon mass (NIOSH 5040)
- **Regeneration** – must provide for adequate regeneration for a vehicle running 50% of the time in excess of 350 Celcius
- **Backpressure** – must meet vehicle/engine warranty!
  - New trap 50 mbar
  - Regenrated trap 60 mbar
  - Before cleaning (maximum) 200 mbar
- **Datalogging** – is needed for tracing problems

INCO DPF Specifications (cont'd)

- **Secondary emissions** (catalysed traps are the concern)
  - **NO2** – preferably no increase of NO2, but in the limit must not exceed the equivalent of 0.8 ppm at a ventilation rate of 100 CFM/HP
  - **Copper** – is not permitted in any catalyst formulation (fuel or filter) due to the potential for increases in dioxin**
- **Robustness**
- **Risk** – CSA & CEC approved, fire suppression systems
- **Useful life** - 3 years or 9000 hours

Acknowledgements

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