The Effect of Maintenance of Diesel Engines on Diesel Particulate Generation

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"It is of particular importance that the fuel entering at the mouth should be thoroughly consumed and without the formation of soot"

Rudolf Diesel - US Patent application 8 August 1898

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Historical Overview (Mining)

- First Reference to Maintenance and emissions in the mining industry-Holz (1960)
  - Research in the UK on the performance of diesel locomotives in coal mines
  - US Bureau of Mines not studied the topic (1960) but suggested:
    - Fuel injection effects combustion
    - Use only OEM replacement parts
    - Injector blockage or wear effects exhaust gases

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Historical Overview (Mining)

- 1977-International workshop on diesels
- 1985-US Bureau of Mines Study
- 2000-DEEP Maintenance project
- 2000-Tower Colliery preliminary study
- 2003-VUT/BHP Billiton Illawarra Coal

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International Workshop 1977

- Speakers from: Australia, Canada, South Africa & USA
  - Working group reported that both engine and exhaust treatment are very important in controlling emissions
  - Referenced statutory requirements designed to control emissions

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US Bureau of Mines -1985

Induced faults in a new Deutz F6L 912W engine and concluded high emissions could be traced to:

- Intake air filter change out frequency
- Fuel injection timing adjustment
- Fuel rate adjustment
- Fuel injector nozzle cleaning or wear
- Exhaust restriction

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US Bureau of Mines - 1985

- Hydrocarbons :
  - Timing adjustment – up 306%
- Carbon monoxide:
  - Intake restriction & excess fuel - up 445%
- Oxides of Nitrogen:
  - Timing adjustment - up 50%
- Particulates:
  - Intake restriction & excess fuel – up 1038%

DEEP Project - 2000

- Team approach to maintenance
- Audit of engine maintenance yearly
- Testing of undiluted exhaust emissions fundamental to maintenance projects
- Training of maintenance personnel key to success

Tower Colliery - 2000

Pre & Post Intake Flame Trap Cleaning-PJB 114

	Total Carbon g/kWhr
Pre Maintenance	0.84 - 1.4
Post Maintenance	0.38 - 0.4

2003 VUT-BHP Billiton Illawarra Coal

- Aims of project were:
  - To test the raw exhaust of as many engines in the company fleet as possible
  - To identify reasons for any abnormal engines.

Methodology

- Raw exhaust gas monitoring using a mobile laboratory
- Raw exhaust particulate monitoring using R&P 5100 DP analyser
- Engines loaded as per MDG 29 (currently used for testing raw exhaust gases)

MDG 29 Engine Load Protocol

- NSW Mines Department Guideline
  - Engine in gear at flight revs
  - Load applied (Torque converter) to lower revs by 10%
  - CO_2 usually 8-10%

Methodology

- Testing of 66 engine exhausts (68% of fleet at four mines)
- Statistical analysis of the emissions so as to establish abnormal engines

Mobile Gas Laboratory

R & P 5100 DP Analyser

On-site Monitoring

No. of Engines Tested & Acceptance Criteria

Engine Type	No. Engines Tested	Mean EC mg/m^3	95% UCL mg/m^3
Caterpillar 3304	26	30	37
Caterpillar 3306	5	10	19
KIA 6- 247	12	56	85
Perkins 1006.6	14	30	42
MWM D916.4	6	40	56
MWM D916.6	3	70	Variance too large

Abnormal Engines

Mine	Vehicle	Engine	EC mg/m^3 (UCL)
A	SMV 5073	Perkins 1006.6	93 (42)
A	SMV 5100	Perkins 1006.6	60 (42)
A	MPV 98	Cat 3304	71 (37)
B	PJB 103	KIA 6-247	102 (85)
C	PJB 114	KIA 6-247	131 (85)
C	PJB 132	KIA 6-247	139 (85)
C	Ram Car 194	MWM D916.6	159 (70+)

Particulate Results Vs Maintenance

Vehicle	Pre Mtce. EC mg/m³	Post Mtce. EC mg/m³	EC g/hr	Maintenance Performed
PJB 132	139	46	9.5	New fuel pump and cleaned scrubber tank
PJB 114	131	40	8.5	New scrubber tank, New injectors, adjusted fuel
Ram Car 194	159	71	11.3	Replaced injectors
PJB 103	102	61	14.5	Replaced injectors, cleaned scrubber tank and intake air system

Blocked Scrubber Tank

Recent Data (Raw Exhaust)

Vehicle	Initial Result (mg/m3 EC)	Post Maintenance (mg/m3 EC)	Maintenance Performed
Eimco 9	166	54	New Injectors
SMV 5076	75	44	Retarded timing, cleaned intake system and reduced fuel
PJB 107	206	80	Cleaned intake system, reduced fuel
PJB 15	150	75	Changed air cleaner

Raw Exhaust Particulate Levels Improvements in the past 5 years

Engine Type	EC g/kWhr (1998-1999 data)	EC g/kWhr (2003-2004 data)
Cat 3304	0.11 – 1.0	0.02 – 0.22
Cat 3306	0.10 – 0.72	0.02 – 0.30
KIA 6-247	0.26 – 1.4	0.04 – 0.57
Perkins 1006.6	0.2 – 0.35	0.03 – 0.25

Monitoring Engine Performance Parameters for Fault Detection

Parameter	Pre (Detection)	Post (Correction)	Expected Value
Stall Speed RPM	1500	1725	≥1700 rpm
Intake Restriction	2	2	≤ 5 kPa
Intake Charge Pressure	110	145	≥ 138 kPa
Exhaust Backpressure	5	5	≤ 7.5 kPa
Fuel Pressure	448	448	≥ 413 kPa
Carbon Monoxide (CO)	405	129	≤ 200 ppm
Bacharach Soot Index	9	6	≤ 6

- Detroit Diesel Series 60 electronic engine
- Fault detection - injectors due to running out of fuel (cavitation)

Factors to be Measured on a Systematic Basis

- **Exhaust emissions**
- **Emissions control device efficiency**
- **Engine stall speed**
- **Intake air restriction**
- **Intake charge air pressure (turbocharger)**

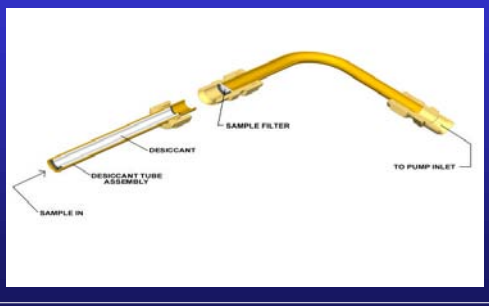
Factors to be Measured on a Systematic Basis

- Exhaust backpressure
- Fuel transfer pump pressure
- Intake charge air temperature
- Engine cooling system differential pressure

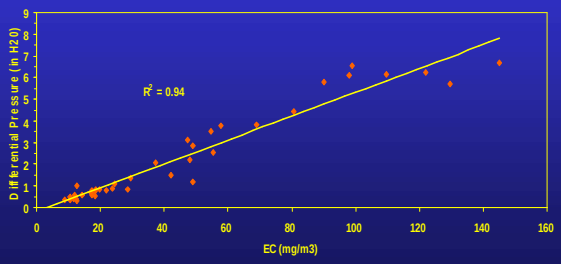
Monitoring Devices for Raw Exhaust DP

NIOSH Instrument (SKC)

SKC Diesel Detective

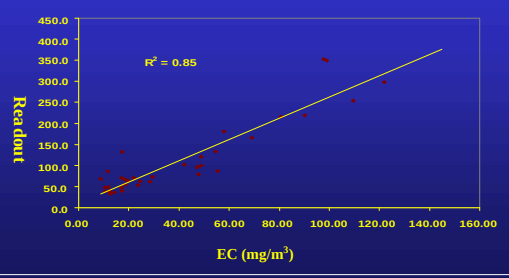


Field Calibration v NIOSH 5040



Air Quality Technologies Instrument

AQT Instrument Readout v EC



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Gas Monitoring Equipment

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Conclusions

- **Basic maintenance significantly effects raw exhaust DP levels**
- **An effective maintenance programme will reduce employee exposure to diesel particulate emissions**
- **Instrumentation to measure raw exhaust DP levels is becoming available**

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