Solid Particle Counting System
SPCS

Cambridge Particle Conference
22\textsuperscript{nd} May 2006
PMP : Solid Particle Number Counting

With the increasing interest in the health effects of particulate emissions and continuing reduction of levels of emission, the PMP (Particulate Measurement Program) was initiated to make a complete review the principles and methods of particulate measurement.

Following the phases of literature study, review of candidate systems and a program of testing/validation, two methods were selected to be used in a global correlation exercise:

- Filter based gravimetric measurement from diluted exhaust as current legislation, with improvements along the lines specified by EPA for 2007 HDD (heated sampling, particle size classification etc)
- Counting the number of solid particles emitted from the vehicle

Draft requirements and regulations were issued for instrument developers and testing authorities / laboratories.
Solid Particle Number Counting

- Measuring range on SPCS: (23 nm ~ 2.5 to 10 μm)
- Volatile particles formed in dilution process

Condensation Particle Counter (CPC)

TSI Model 3010D is used in the SPCS prototypes

Design is modified to give the particle size classification specified in the GRPE-PMP draft regulation

Reference: TSI CPC 3010 manual
Schematic To Meet GRPE-PMP

Additional Equipment Required
CPC Calibration Aerosol Generator
- 30, 50, 100, 300 nm @ 10,000 particles/cc

CPC Calibration Aerosol Generator (2)
- 20, 100, 300, 500, 700 nm for PND verification?

Aerosol Diluter
- minimum 5 concentrations, equally separated from 0 - 100% of concentration

C40 Particle Generator
using tetracontan (C40)
- > 1000 particles/cm3 with 30nm diameter

Sample Points
- Primary Tunnel
- Secondary Tunnel
- Partial Flow Tunnel
Depending on regulation

System will include gas connection points for
- tracer gas injection
- tracer gas measurement

HEPA Filter (99.95%)
Air (humidity?)

< 1 particle/cc when HEPA air injected at CPC inlet

< 10 particle/cc when HEPA air injected at VPR inlet

47 deg C

Cyclone
Heated Diluter (PND1)
DF = 1 -1000
Particle Generator Unit
(> 10^4 particles/cc @ 30 - 100 nm)
Aerosol Diluter (min 5 points)
Evaporator Tube
300 - 400 deg C
350mm / 6mm
Cold Diluter (PND2)
DF = 1 -30
Diluter stage to reduce temp w/o particle loss

bv
Flow meter
Air
Vent
CPC (Counter)
Vent

Overall System Automation Controller
- Monitoring and Display
- Local / Remote Control
- Host Interface / Reporting
SPCS Wide Range Diluter

- No moving parts
- Low dead volume
- Accurate dilution ratio
- Minimum contamination
- Used as PND1 and PND2

- Ideal for remote control
- Wide dilution ratio range
- High penetration for particles
- Not sensitive to sample pressure (with PID control)
Prototype System Appearance

Front

Back
Fully Automated Control on Prototype

- Control and data acquisition with NI Fieldpoint process I/O and Labview software
- Automated operations including check functions
- Configurable data log
- Data log rate up to 5 Hz
- Real-time dilution ratios
- Easy to operate
Key Requirements For SPCS (PMP specifications)

- Daily linearity check, using particle generator and particle gas divider \( (R^2 > 0.95) \)
- Confirmation of the dilution ratios \( (+/- 10\%) \)
  - Using gas tracer method and actual single size particles
- Removal of particles from volatile HCs \( (> 90 \%) \)
  - Using tetracontan (C40) vaporiser into Evaporation Tube
- Low losses of solid particles \( (< 10 \%) \)
  - Using particle generator and single particle size selection to confirm the solid particle penetration through the system at various sizes
Daily Linearisation Check (Automatic)

\[ y = 0.994x - 33.463 \]
\[ R^2 = 0.9997 \]

Standard water
Orifice at generator: 5mm
Pressure: 30 psi g
Dilution Ratio Check

Using propane and FID as tracer gas
Removal Of Volatile HC Particles
Evaporation Tube Temperature Dependency

*C40 concentration (100 nm particles) downstream of EU as the function of temperature set point*
Volatile Particle Removal Efficiency

*C40 concentration (100 nm size) downstream of EU as the function of set point*

Removal > 99%
Particle Losses In SPCS

Penetration > 98%

![Graph showing particle losses with Log Dp and dN/dLogDp on the y-axis and Log Dp on the x-axis. The graph includes data points for Raw, DR 500, DR 750, and DR 1000 filtrations. The legend indicates penetration levels of 20x25, 30x25, and 40x25. The graph demonstrates that penetration is greater than 98% for all filtrations.]
Initial Testing, Diesel On Chassis Dyno

Diesel vehicle (1997)

<table>
<thead>
<tr>
<th>Day</th>
<th>Conc. (part/km)</th>
<th>difference (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Day I</td>
<td>4.837E+13</td>
<td>0.00%</td>
</tr>
<tr>
<td>Day II</td>
<td>4.898E+13</td>
<td>1.26%</td>
</tr>
<tr>
<td>Day III</td>
<td>4.833E+13</td>
<td>-0.08%</td>
</tr>
</tbody>
</table>

Total dilution Ratio: 1250 (50x25)
### SPCS In PMP Inter - Lab Correlation

<table>
<thead>
<tr>
<th>Part</th>
<th>No</th>
<th>Lab:</th>
<th>PMP testing period:</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>1</td>
<td>VELA, JRC, Italy</td>
<td>9 to 17 November</td>
</tr>
<tr>
<td>A</td>
<td>2</td>
<td>AVL MTC, Sweden</td>
<td>29 November-3 Dec 04</td>
</tr>
<tr>
<td>A</td>
<td>3</td>
<td>Ricardo Consulting Engineers, UK</td>
<td>Mid January 05</td>
</tr>
<tr>
<td>A</td>
<td>4</td>
<td>Lab of Applied Thermodynamics (LAT), Greece</td>
<td>Early February 05</td>
</tr>
<tr>
<td>A</td>
<td>5</td>
<td>RWTÜV, Germany</td>
<td>Late February 05</td>
</tr>
<tr>
<td>A/B</td>
<td>6</td>
<td>VELA, JRC, Italy</td>
<td>March 05</td>
</tr>
<tr>
<td>B</td>
<td>7</td>
<td>NTSEL, Japan</td>
<td>April - Transfer to Japan</td>
</tr>
<tr>
<td>B</td>
<td>8</td>
<td>National Motor Vehicle Emission Research Lab, Korea</td>
<td>Early May 05</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Interim Report</strong></td>
<td><strong>June 05 – Transfer to Europe</strong></td>
</tr>
<tr>
<td>B</td>
<td>9</td>
<td>Shell, UK</td>
<td>July 05</td>
</tr>
<tr>
<td>B</td>
<td>10</td>
<td>UTAC, France</td>
<td>Late July 05</td>
</tr>
<tr>
<td>B</td>
<td>11</td>
<td>VELA, JRC, Italy</td>
<td>August-September 05</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Final Report</strong></td>
<td><strong>October-November 05</strong></td>
</tr>
</tbody>
</table>
SPCS In PMP Inter - Lab Correlation

PEUGEOT 407

Golden Car

Golden System
SPCS In PMP Correlation Exercise

Particle emission from different vehicles

Outline of tested vehicles

<table>
<thead>
<tr>
<th></th>
<th>Fuel</th>
<th>Disp.cm³</th>
<th>Engine type</th>
<th>After treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>GV</td>
<td>Diesel</td>
<td>1997</td>
<td>TC, Common rail D.I</td>
<td>SiC DPF</td>
</tr>
<tr>
<td>JV-1</td>
<td>Gasoline</td>
<td>2990</td>
<td>NA, Direct Injection</td>
<td>TWC + de NOx Cat.</td>
</tr>
</tbody>
</table>

Repeatability of measurement by GPMS and SPCS

Inter-Lab Correlation Exercise @NTSEL
Particle Trap Efficiency Measurements

JE05 Driving mode

Before Device
After Device

Particle Number Before DPNR

Particle Number After DPNR

Time sec
SPCS Actions after ILCE

- Prototype SPCS updated after ILCE in Japan
  - minor modifications incl software

- Prototype SPCS in the HE Chassis Cell
  - Testing on EU spec vehicles and cycles
  - Comparison with other PM measurements
    - Full flow dilution CVS with gravimetric PM
    - TEOM (on CVS/DLT)
    - MEXA-1230PM on direct raw exhaust with a standalone PTFM (Pitot Tube Flow Meter)
SPCS Data in HE Test Cell

MEXA-1230PM
Raw exhaust is diluted then soot content is measured using DC Sensor

SOF is measured from raw exhaust using HFID differential method (190 / 47 deg C)

Soot / SOF concentrations are converted to mass base using real time exhaust flow rate from PTFM

Heated Ejector Diluter

CVS SYSTEM

Particle Filters

DLS-7100 E SPCS

Gravimetric PM Mass is measured using a conventional dilution tunnel, CVS and particulate sampler

SPCS unit samples from the dilution tunnel directly with fast bypass into integrated cyclonic separator and then particle dilution and counting

PITOT TUBE FLOW METER

Explore the future
© 2005 HORIBA, Ltd. All rights reserved.
Vehicle comparative data shown above includes diesel w/o DPF, diesel with new and used DPF, gasoline MPI with TWC with cold and hot starts.
Vehicle comparative data shown above includes diesel w/o DPF, diesel with new and used DPF, gasoline MPI with TWC with cold and hot starts
Vehicle comparative data shown above includes diesel w/o DPF, diesel with new and used DPF, gasoline MPI with TWC with cold and hot starts
Vehicle comparative data shown above includes diesel w/o DPF, diesel with new and used DPF, gasoline MPI with TWC for cold and hot starts
SPCS Future Actions

- SPCS prototypes (2 sets) will be taken to JRC ISPRA for final session of PMP Inter Lab Correlation Exercise
- SPCS has been offered for use in the HDD Particle Number Program
- Timing for if and when a particle number regulation will be applied remains open
- EU Auto Industry representatives and individual manufacturers have objected to the inclusion of particle number counting in the draft LD Stage 5 regulations
  - Current absence of practical, traceable calibration/verification system
- Prototype SPCS results shows good potential for a highly sensitive soot measurement system
- Production SPCS scheduled for deliveries in April 2007.