Development of a methodology for in-board assessment of the efficiency of air quality filters

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1. Assessment of the filter efficiency $\rightarrow$ real conditions

2. Exposure: mean concentration

3. Particle characterization

State of the art:
- In lab
- Proposal of Qabine: \textit{in situ} (highways in Paris)
Challenges

1. Instrumentation
2. Sampling point: speed
3. Sampling point: place, direction
4. Transfer efficiency: assessment, improvement
5. Test *in situ*
Challenge 1: Instrumentation

Optical techniques

Most used approach: optical techniques
- Easy-to-use
- Mobile
- Real time information (down to 1s)

Limitations:
- Calibration with « perfect » particles
- Volumetric mass: only 1 value, to be chosen
- Optical diameter
- Cannot detect particles < 300 nm

Reference Method: gravimetry
Challenge 1: Instrumentation $\rightarrow$ decision

Reference method = gravimetry

impactor DEKATI

$\Rightarrow$ Cascade impactor
$\Rightarrow$ PM1, PM2.5, PM10
$\Rightarrow$ Weighing: EN12341

Nota: high flow (30 lpm)

Sampling points:
- Upstream the filter
- Indoor air in the car
  (« downstream »)
Challenge 2: outdoor sampling

Speed at the sampling point:
In ambient air; in-tube
Need for a STABLE speed in ambient air!
Challenge 2: outdoor sampling → decision

Is it possible to stabilize the speed for upstream sampling?

INLET
Challenge 2: outdoor sampling

Is it possible to stabilize the speed for upstream sampling?

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**Speed measurement upstream the ventilation system, versus the wind speed – for 5 ventilation rate**

<table>
<thead>
<tr>
<th>Wind speed (km/h)</th>
<th>Upstream speed (km/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.03</td>
</tr>
<tr>
<td>20</td>
<td>0.3</td>
</tr>
<tr>
<td>40</td>
<td>1.26</td>
</tr>
<tr>
<td>60</td>
<td>1.27</td>
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<tr>
<td>80</td>
<td>1.43</td>
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<tr>
<td>100</td>
<td>1.9</td>
</tr>
<tr>
<td>120</td>
<td>2.14</td>
</tr>
<tr>
<td>140</td>
<td>2.41</td>
</tr>
<tr>
<td>160</td>
<td>2.76</td>
</tr>
<tr>
<td>180</td>
<td>2.73</td>
</tr>
<tr>
<td>200</td>
<td>2.76</td>
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<tr>
<td>220</td>
<td>2.76</td>
</tr>
<tr>
<td>240</td>
<td>3.19</td>
</tr>
<tr>
<td>260</td>
<td>3.5</td>
</tr>
</tbody>
</table>

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**Wind tunnel tests**

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**Results:** for pale 1 to 4, below 80 km/h,
- The upstream wind speed is related to the car ventilation, **not to** the ambient air speed
- So it is possible to sample particles with a stable speed in the sampling environment

=> Pale 2
Challenge 3: sampling point and sampling direction

**air flow modelling**

**Results:** for pale 2, at 80 km/h,
- Same order of magnitude than measured speed
- Confirmation that the upstream wind speed is defined by car ventilation
- Selection of a sampling point out of the recirculation zone
- Sampling direction // to the air flow
Challenge 4: definition/optimisation of the sampling line

Particle losses - calculation

(Sampling efficiency) x (Transport efficiency) = Transfert efficiency

=> Software
Particle Loss Calculator
State of the art
[Baron et Willeke, 2005]

Calculation of the Transfert Efficiency

Optimisation
Challenge 4: definition/optimisation of the sampling line

Efficiency versus diameter for a first sampling line

- DEKATI on the passenger seat
- Different diameters for the tubing
- 3 changes of direction
Challenge 4: definition/optimisation of the sampling line

Sensitivity study

- Example: impact of the aspiration angle
Challenge 4: definition/optimisation of the sampling line

optimisation

Etude d’une nouvelle ligne de prélèvement

Improvements:
- Shorter tubing (~50%)
- 3 changes of direction => 1 slight
- Larger diameter
Comparison with the previous sampling line:
✓ Particles d(1 µm) => 80 à 94 %
✓ Particles d(2.5 µm) => 32 à 76 %
✗ Particles d(> 4 µm) => < 50 %

(1 ; 94 %)
(2.5 ; 76 %)

✓ PM1
✓ PM2.5
✗ PM10

The sampling line is
- not validated for PM10
- Validated for PM1 and PM2.5
Challenge 5: *in situ* testing

**Particle losses - calculation**

<table>
<thead>
<tr>
<th></th>
<th>Average of the filtration efficiency</th>
<th>Number of validated experiments</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PM1</td>
<td>PM2,5</td>
</tr>
<tr>
<td>Filter A</td>
<td>54 %</td>
<td>59 %</td>
</tr>
<tr>
<td>Filter B</td>
<td>53 %</td>
<td>55 %</td>
</tr>
</tbody>
</table>

Représentation graphique des efficacités de filtration des PM1 pour le filtre B en fonction de la concentration en PM1 en extérieur.

Représentation graphique des efficacités de filtration des PM1 pour le filtre A en fonction de la concentration en PM1 en extérieur.
Conclusion and Perspectives

**Objective:** Conception of a sampling line for the assessment of the filtration efficiency of the filter

**Results:** Methodology
- PLC Study + wind tunnel + CFD + car changes
- Validated for PM1 and PM2.5
- Tested on 2 filters

**Limitations:**
- Car changes => Professionnal
- method not validated for PM10
- PM2.5: uncorrected values
- Downstream sampling point: not at the outlet
- Upstream point: dedicated to filter efficiency meas., not to ambient air characterisation

**Perspectives:**
- To develop a specific downstream sampling point
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Thanks for your attention!