3D characterisation of the structure of activated carbon packed beds using X-ray microtomography

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Introduction

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Activated carbon

Water treatment

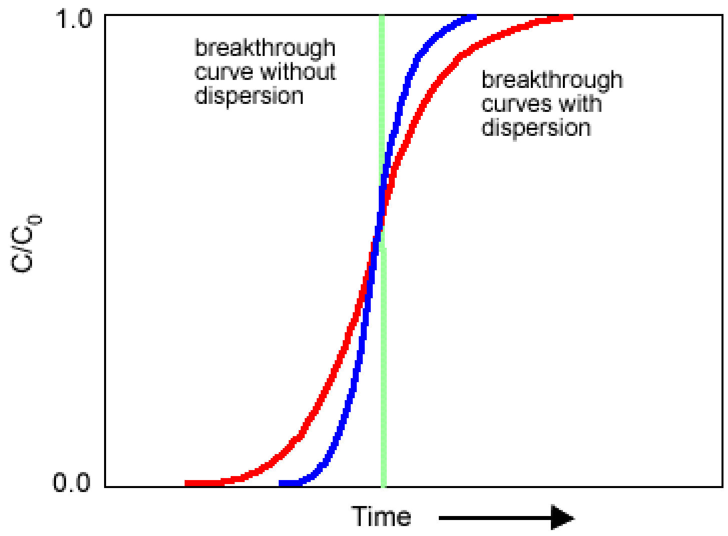
Air treatment

Individual protection

Catalyst support

Importance of packing structure

- Adsorption of pollutants within carbon filters characterized by a breakthrough curve
- Sharp adsorption front: more efficient removal process
- Shape of the breakthrough curve depends on two main factors
  - Texture of the adsorbent at the nanometric scale
  - Macroscopic transport in the bed
- Impact of the packing structure on the gas transport
  - Maldistribution
  - Impact of tube-to-particle diameter ratio
  - …



- Importance of 'in-situ' characterisation of the packing structure
- Microtomography = powerful tool for non destructive packing investigation

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Materials and methods

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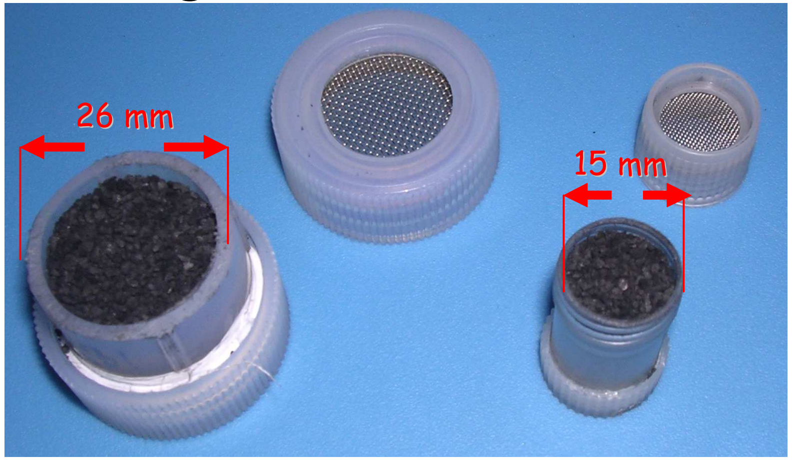
Activated carbon filters

- Plastic canisters
  - Length: 33 mm
  - Diameter: 15 and 26 mm
    - → influence of tube-to-particle diameter ratio
- Polydispersed commercial granular activated carbon
  - Chemviron Carbon BPL
  - 2 and 7 depending on the filter diameter



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X-ray microtomograph

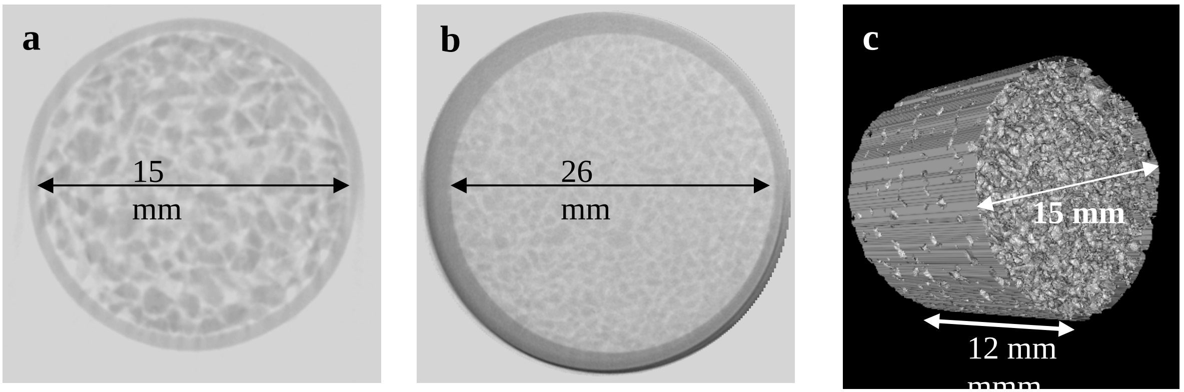
Skyscan-1074 X-ray scanner

- **Source: 40 kV-1 mA**
- **Detector: 768 x 576 pixels**

  8-bit camera
- **Pixel size: 41 µm**
- **Rotation step: 0.9°**
- **Acquisition time: ≈ 10 minutes**
- **Cone-beam filtered backprojection reconstruction**

Image analysis

- 3D image processing
  - Image filtering
  - Segmentation between carbon grains and voids
- Quantitative measurements
  - Void fraction
  - Void size distribution using opening size granulometry
  - Radial void profiles



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Results

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Void fraction

- Comparison between results obtained from image analysis and physical measurements

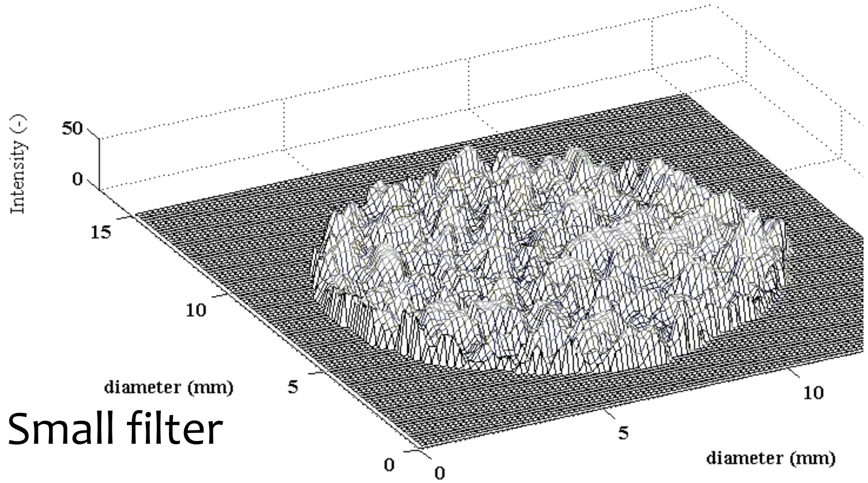
$$\delta_p = 1 - \frac{M}{\rho \cdot V}$$

δ_p = void fraction (-)
M = weight of carbon in the filter (kg)
V = volume of the packed bed (m^3)
ρ = carbon bulk density (kg/m^3)

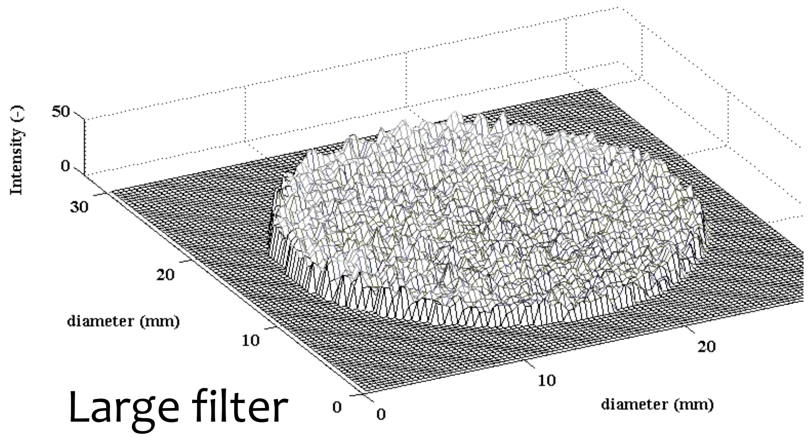
	Image analysis	Physical measurement
Small filter	0.35	0.32
Large filter	0.30	0.26

Void size distribution

- Grey level intensity distribution within a cross section
  - Valleys = carbon grains (low grey levels)
  - Peaks = interstitial voids (high grey levels)



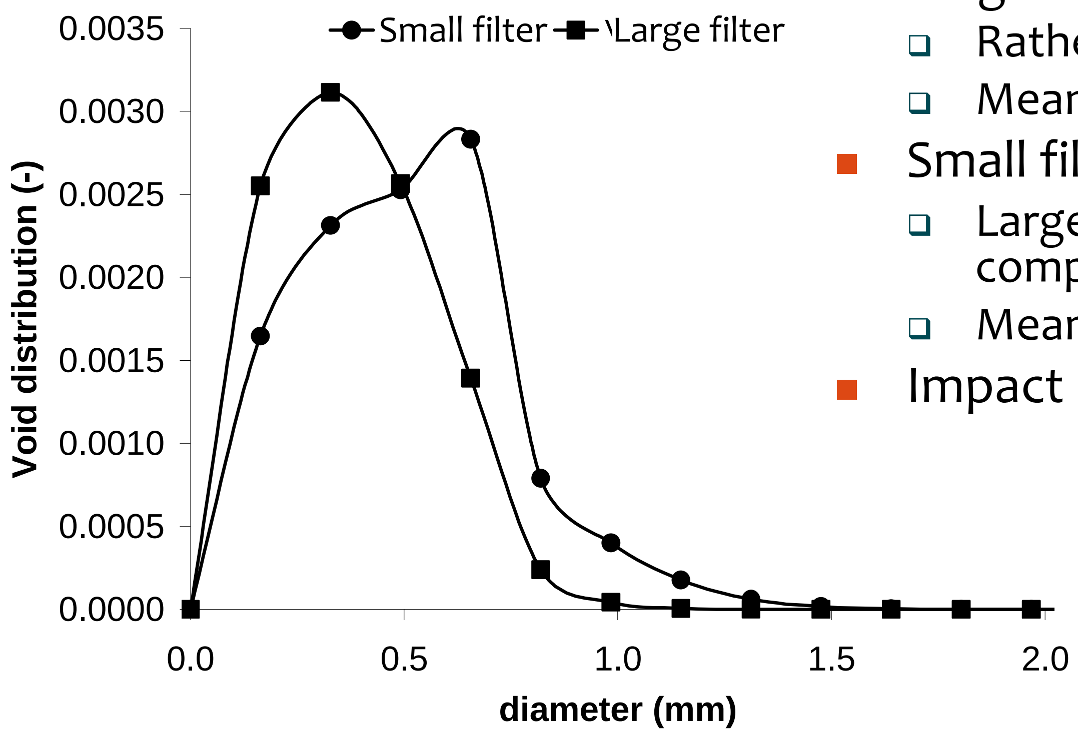
Small filter



Large filter

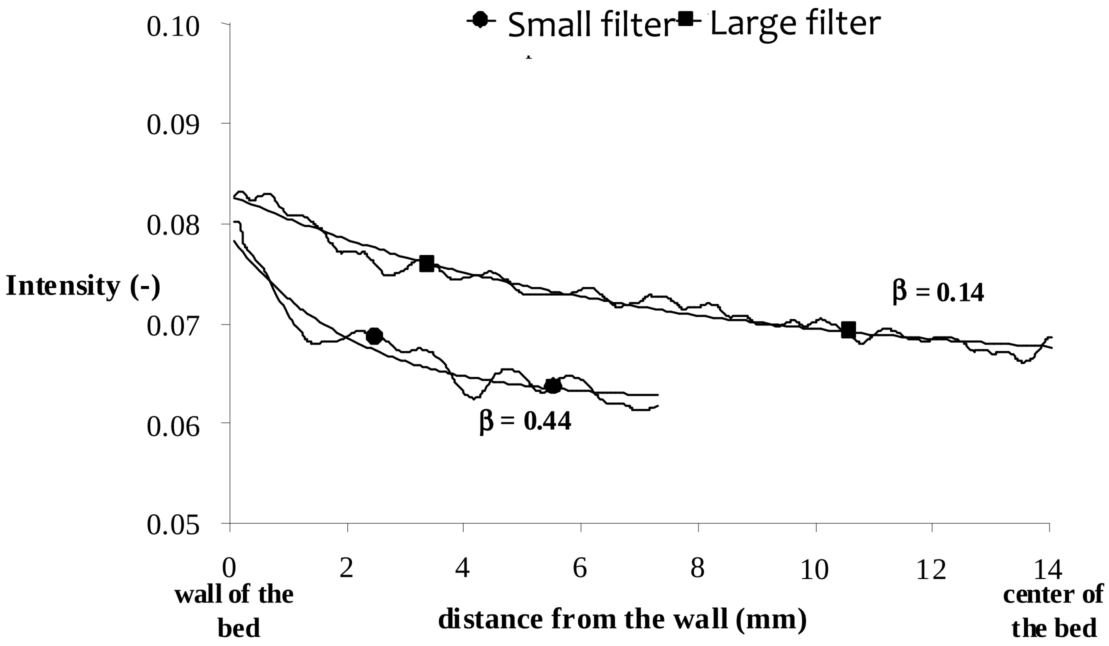
- Smoother patterns for the large filter

Void size distribution



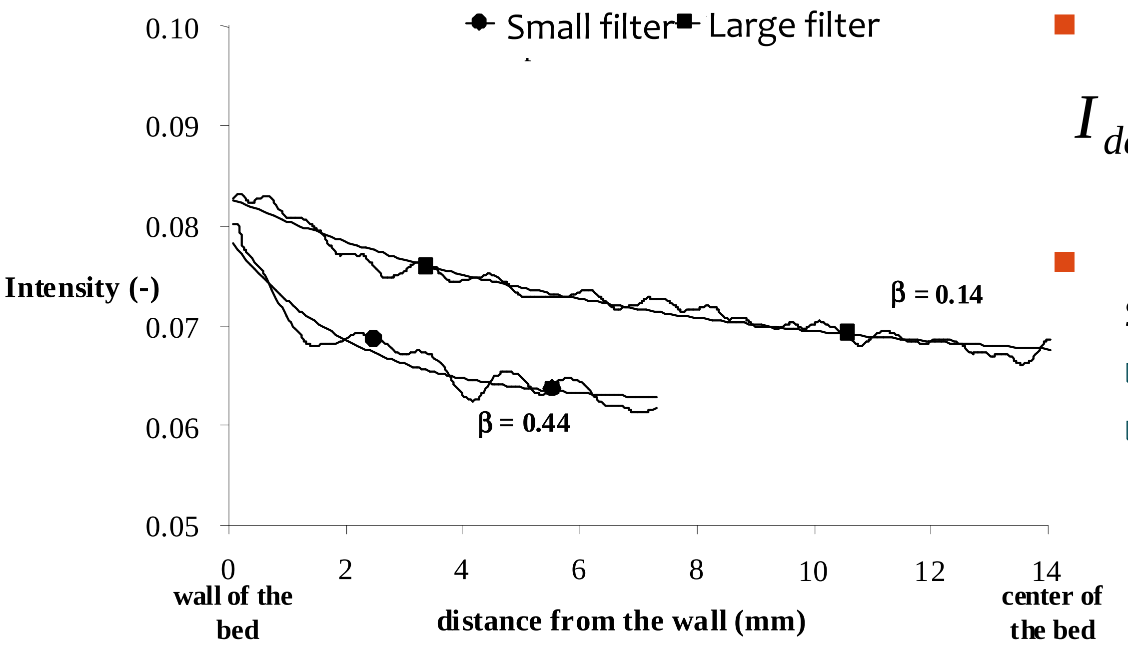
- Large filter
  - Rather normal distribution
  - Mean void size = 0.38 ± 0.09 mm
- Small filter
  - Larger distribution with a more complex shape
  - Mean void size = 0.50 ± 0.12 mm
- Impact of filter size on the gas flow !

Radial profiles



- Decrease of grey level intensity from the wall to the center
  - Wall effect: carbon concentration higher in the center
  - Higher porosity at the wall → channelling effect
- Oscillatory behaviour at a smaller scale
  - Damped oscillations supposed to reach a constant value at high tube to particle diameter ratios

Radial profiles



- Fit with a monotonic exponential

$$I_{decay}(r,\mu) = A(\mu) + B(\mu)e^{(-\beta r)}$$

- Larger decay constant for the small filter: β = 0.44
  - Less uniform distribution
  - Larger carbon gradient concentration from the wall to the center

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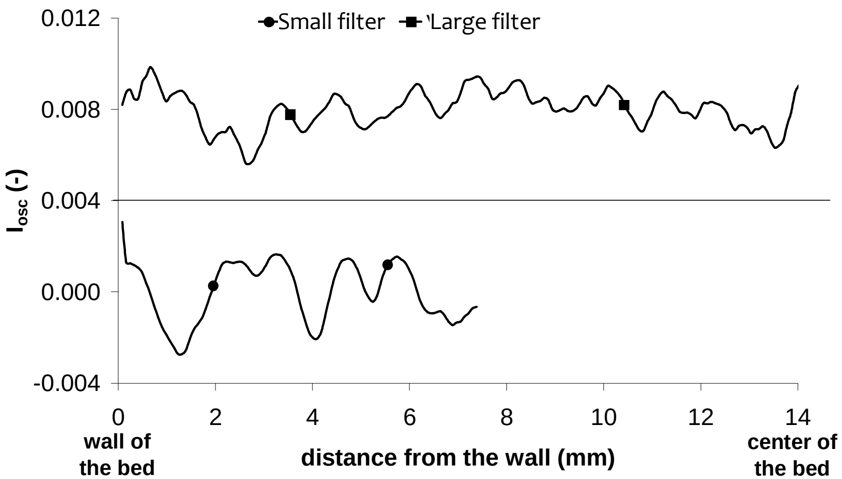
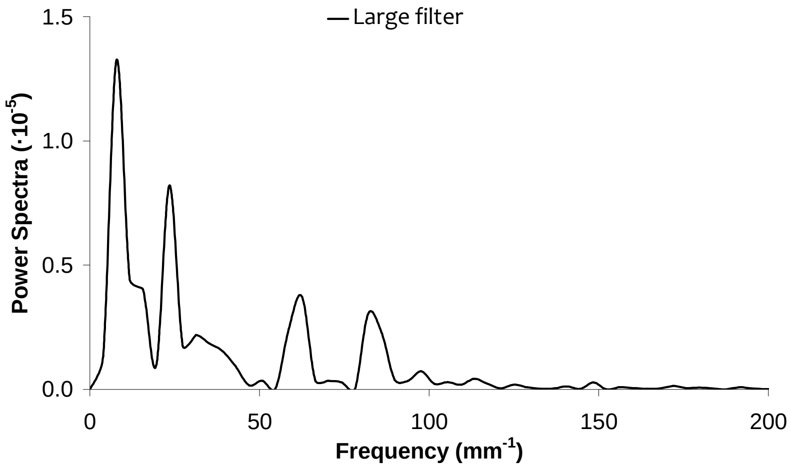
Radial profiles

- Analysis of the oscillating behaviourFit with a monotonic exponential
  - Substraction of fitted radial profiles from measured ones

$$I_{osc}(r) = I(r) - I_{decay}(r)$$





- No clear periodic behaviour for the small filter → uneven packing
- Periodic behaviour for the large filter → power spectra
  - Main peak at a frequency of 7.12 mm^{-1}
  - Characteristic length = 0.8 mm → diameter of carbon grain
  - Packing 'layer by layer' in the filter

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Conclusions

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Conclusions

- X-ray microtomography coupled to image analysis= powerful tool to characterise the 3D structure of activated carbon beds
- Total void fraction in agreement with physical measurements
- Results in agreement with well-known packing beds features
  - Influence of tube-to-particle ratio
    - The larger this ratio, the more uniform the void size distribution
    - Important wall effects for small ratios

Perspectives

- Determination of tortuosity and connectivity
- Setting up relations between packing microstructure and motion of adsorbate concentration front in the bed → in situ follow up X-ray microtomography
- Use of 3D images to simulate the filter operation by the lattice Boltzmann methodology
  - First step = simulation of gas flow
  - Second step = coupling between gas flow pattern and adsorption

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