Deposition, reduction and transformations of diesel particulate matter in a novel open substrate

Deposition, Reduction and Transformations of Diesel Particulate Matter in a Novel Open Substrate

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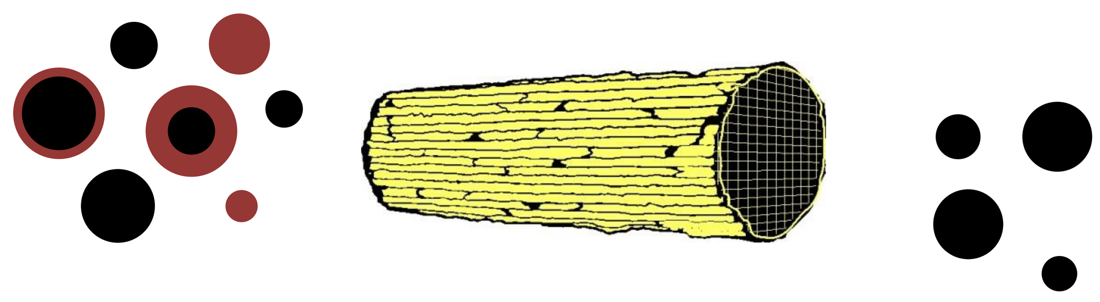
Introduction

- Particulate Matter (PM) emission causes problem for human health as well as for the environment
- Open filters (monolithic flow-through reactors with low pressure drop) have a potential for energy-efficient reduction of PM and, for some applications, may even suffice
- Designs that enable high mass transfer rates towards the catalytically active walls and with enhanced mixing in the gas phase are of considerable interest
- Detailed understanding of capture related phenomena in such substrates is needed
- An open substrate can be used as an *in-situ* analyzer for the HC content of the PM [1]

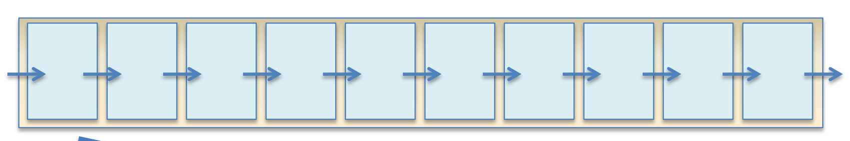


$$CE = \frac{PSD_{before} - PSD_{after}}{PSD_{before}}$$

The conceptual model

- Sigmoid functions to describe HC contents [1]
- Pure volatiles and semivolatile HC (solid core)
- Assuming heavy hydrocarbon ($C_{40}H_{82}$)
- 8 adjustable parameters, fitted to experimental data by gradient search method (lsqnonlin)

Tanks-in-series model (Matlab)



$$CE_{channel} = 1 - PE_{channel} = 1 - e^{-\frac{h_m A_s}{Q}} \qquad h_m = \frac{D_p Sh}{d_{ch}}$$

$$\frac{d(d_p)}{dt} = \frac{2M\alpha_c(p_\infty - p_d)}{\rho_p N_A \sqrt{2\pi m k_B T}} \qquad D_p = \frac{k_B T C_C}{3\pi\mu d_p}$$

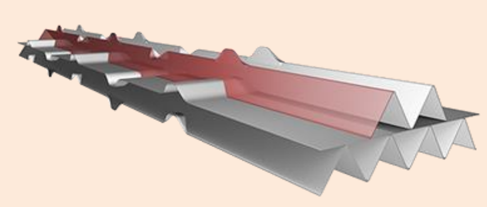
Objectives

- To assess the potential benefits of using a novel open substrate
- To use an inert monolith to enable *in-situ* monitoring of the PM HC content
- To assess the effects of deposition, reduction and transformations of PM separately

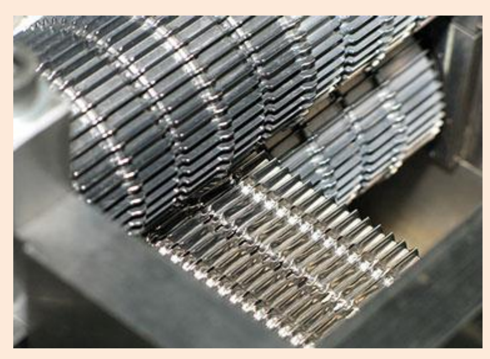
Properties of the novel substrate

- The substrate consists of a flat corrugated foil, joined by the means of a "tongue-and-groove" system
- Obstacles (*"Ecoflow generators"*) in the channels are shaped and placed to generate a specific flow pattern

- More favorable relation between the back pressure and the mass transfer rate than for laminar flow



- Illustration of the foil ↑→



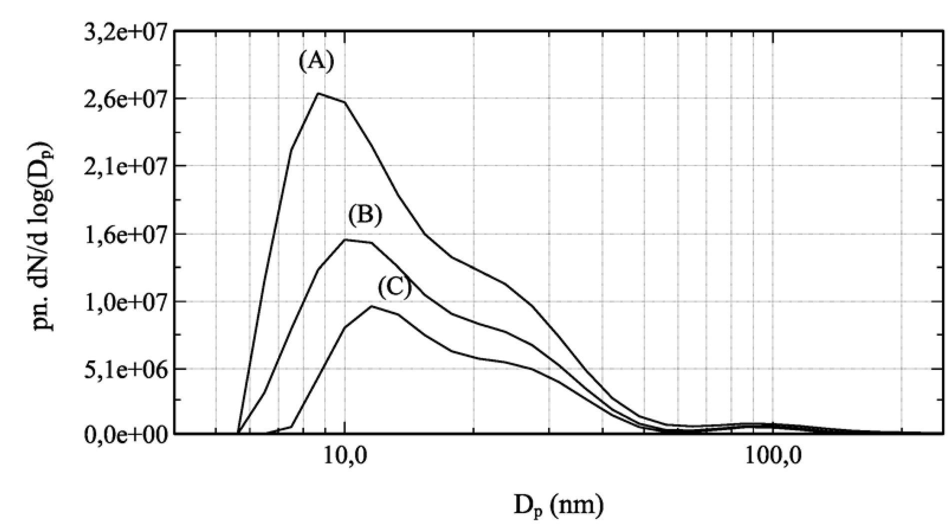
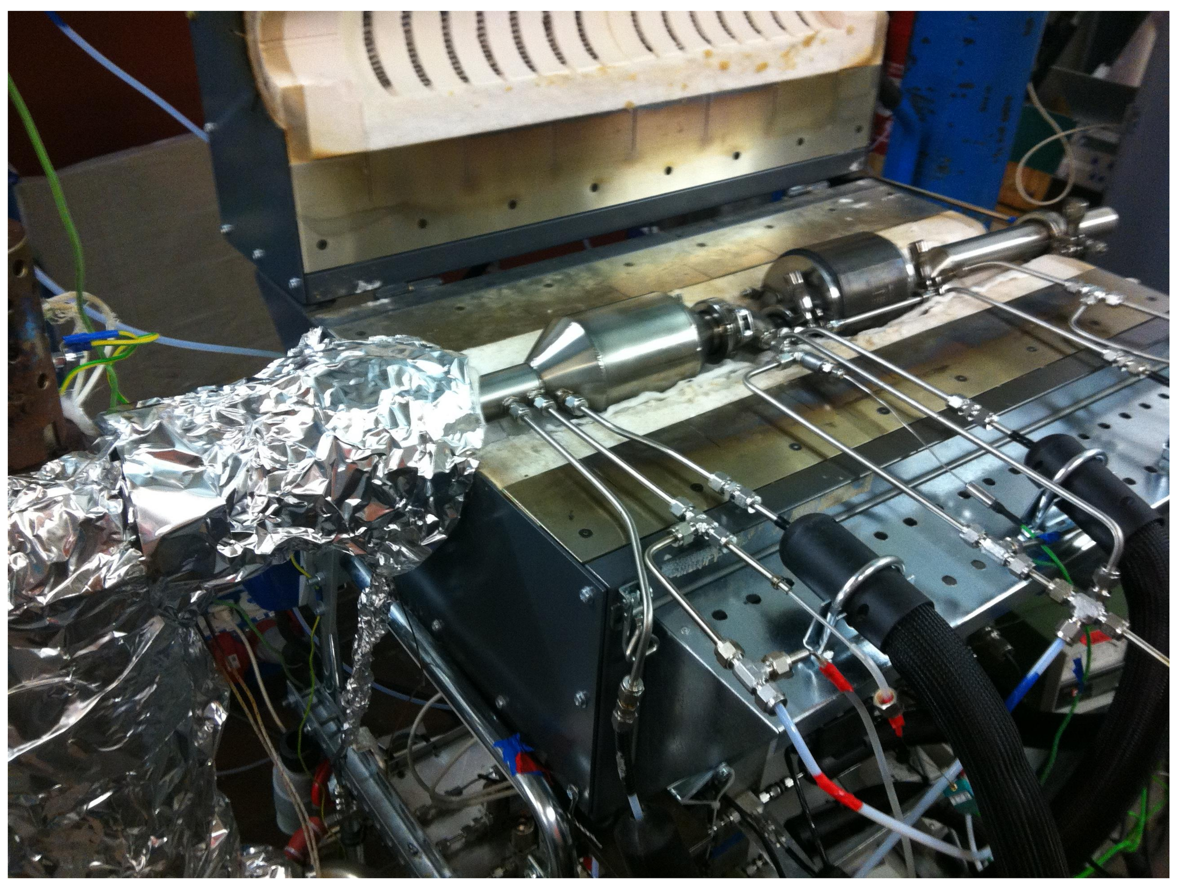


Figure 1. Particle size distributions measured before an inert monolith (A), and before (B) and after (C) the entrance to the novel open substrate. The retention time in the inert monolith is 0.087 s and that in the novel substrate is 0.011 s.



Investigations of the PM capture efficiency in the novel substrate

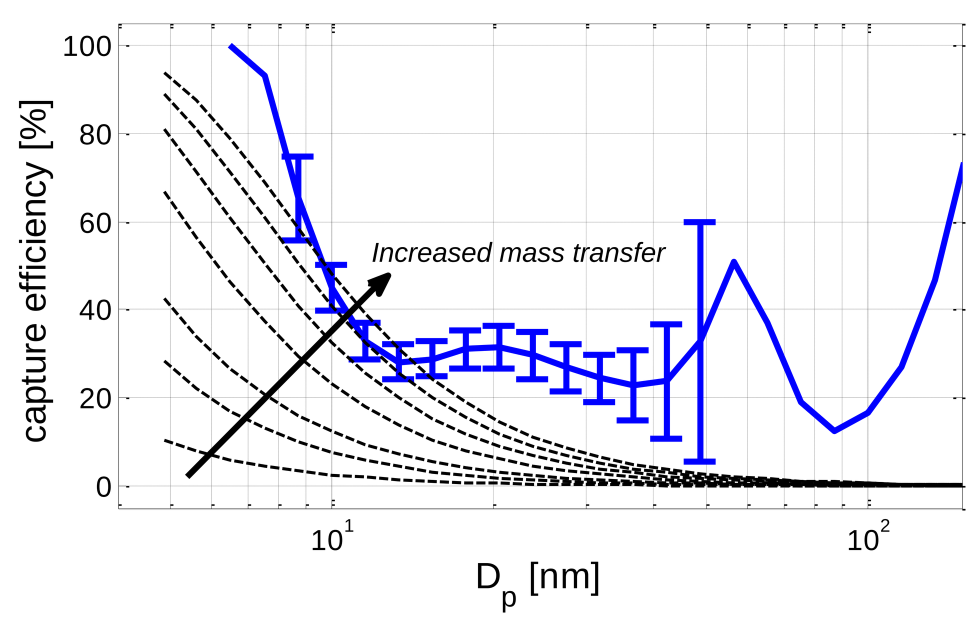


Figure 2. Capture efficiency in the novel open substrate as a function of the particle size (for the same experimental conditions as in Figure 1) – comparison between experimental results and model calculations using varying gas phase mass transfer rates.

Experimental

- EATS (Exhaust Aftertreatment System) [4]
- Insulated, inert substrate placed before the novel open substrate
- Design of Experiments in temperatures, flows and substrate lengths
- PSDs measured in three locations
- Experimental conditions for the data in Figures 1 & 2:
  - Heavy duty single cylinder engine: 2.0 dm^3, cr = 17, 1200 rpm, 120 Nm
  - Common rail injection system: P_{inj} = 1500 bar, SOI = 10 CAD_{btdc}
  - Boost pressure 1000 mbar, EGR = 16%
  - PM instrument: DMS 500, $T_{sample\ line}$=75 °C, $P_{instr.}$=0.25 bar, 1dil=4, 2dil=16
  - Substrate: T = 250°C, Retention time = 0.011 s, $Re_{channel}$ ≈ 400

Conclusions

- Novel open substrate exhibits enhanced PM reduction due to efficient combined PM oxidation and deposition within the specially designed channels
- PM measurements over an inert monolith together with the conceptual model offers a pathway to *in-situ* predictions of the PM properties in the filter

Performance of the novel substrate

- Particle size distributions measured before and after substrate (Fig. 1)
- PM reduction compared to model calculations (Fig. 2)
- Enhanced PM reduction owing to the channel design (i.e. global Sherwood number significantly higher than in a straight channel of constant cross-section)
- Enhanced reduction of the smallest PM cannot be described by a mechanism involving deposition onto the channel walls, and the inert substrate has stripped the PM of all easily desorbed hydrocarbons
- Oxidation of the smallest PM is attributed to gas-phase reactions enabled by a prolonged retention time and enhanced gas-phase mixing in the novel substrate

References

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[4] Sjöblom, J., *Top. Catal.* 56, 287 (**2013**).