Magnetic Resonance Imaging of Gas Flow in a Diesel Particulate Filter

N. P. Ramskill[a], **L. F. Gladden**[a], **A. P. E. York**[b], **A. J. Sederman**[a], **T. C. Watling**[b]

[a] Department of Chemical Engineering and Biotechnology, University of Cambridge, Cambridge CB2 3RA, UK
[b] Johnson Matthey Technology Centre, Blounts Court, Sonning Common, Reading RG4 9NH, UK

(Corresponding author's e-mail: npr24@cam.ac.uk)

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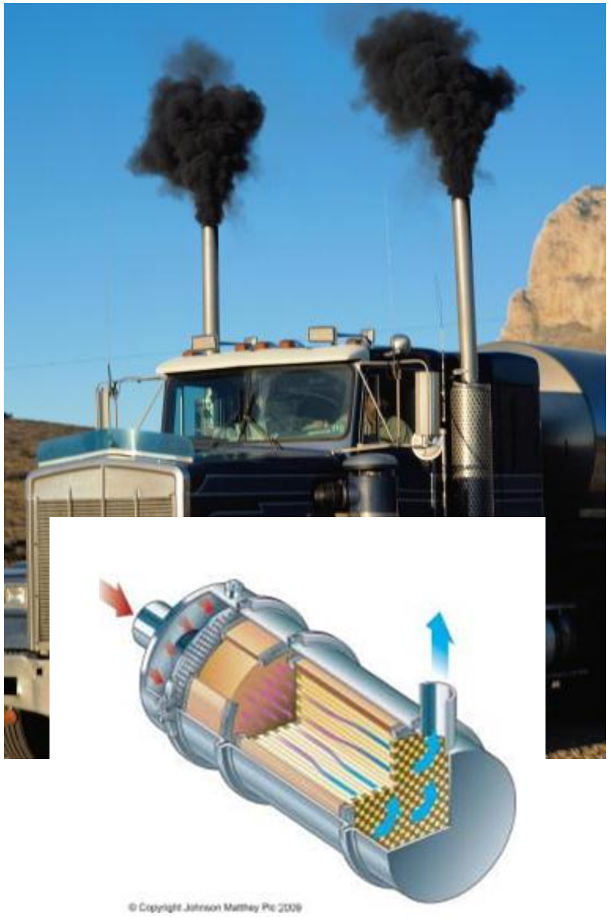
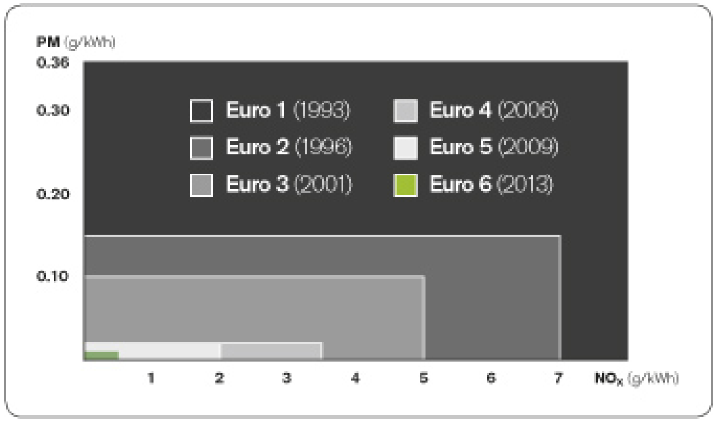
Department of Chemical Engineering and Biotechnology

Outline of the talk

- Introduction to DPFs
- Motivation for the study
- Brief background on MRI
- Experimental details
- Gas flow velocity imaging in a DPF
- Effect of PM-deposition on gas flow in a DPF
- Summary

Introduction





Motivation

- **The primary function of a DPF is for the removal of PM and abatement of the harmful species**

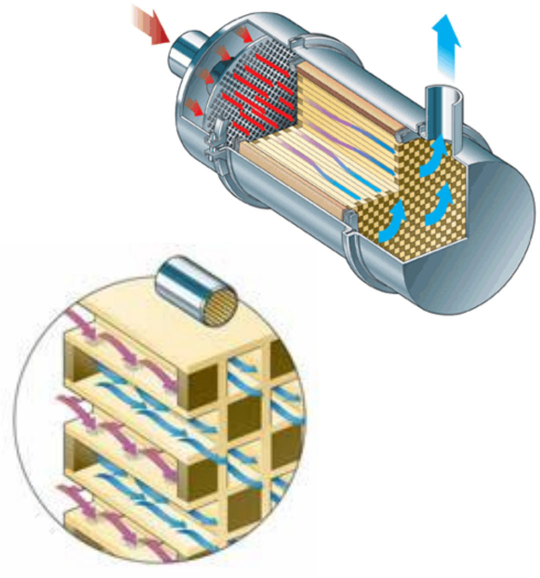
- **These processes do not occur in isolation, but in combination with the engine**

    - **fluid dynamics of the exhaust gas must also be considered**

- **Much of the work in the literature has been computational modelling [1,2]**

- **MRI has been used to *non-invasively* investigate the gas flow in a DPF**

    - **provide further insight into the physical processes taking place**

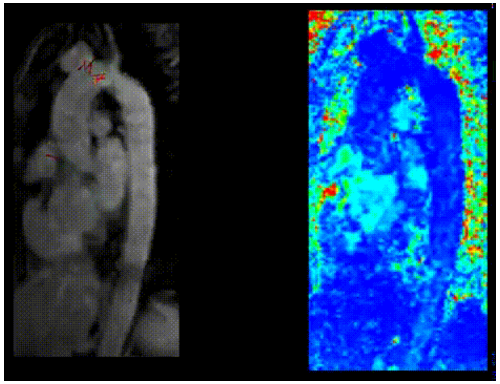


1. Konstandopoulos et al. (2012) Catal. Today., **188** 1 pp. 2-13
2. Bisset (1984) Chem. Eng. Sci., **39** 7-8 pp. 1233-1244

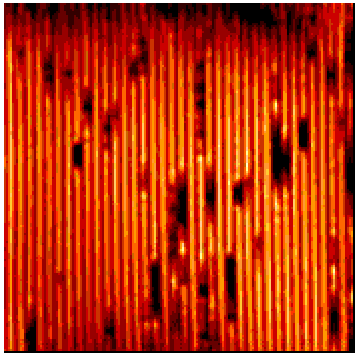
Why use MRI?

- **Typically regard MRI as a medical imaging technique**
  - **non-invasive**
  - **can be used to study opaque systems**
  - **chemically sensitive**
  - **motion sensitive**
- **Utilise these properties to study engineering systems**

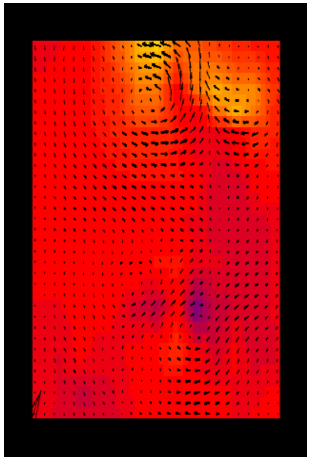
MRI visualisation of blood flow
MRI brain scan



- **Heterogeneous catalysis**
  Taylor flow in a monolith [3]

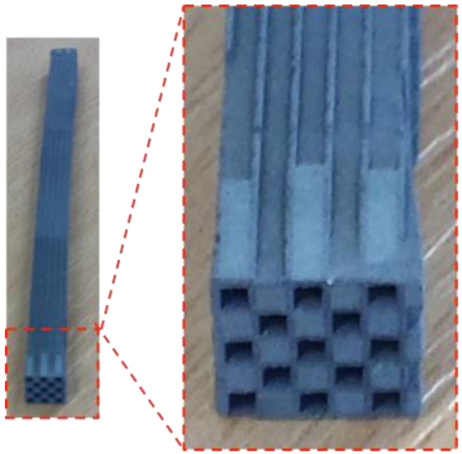


- **Multiphase flow**
  Velocity maps about a single rising bubble [4]

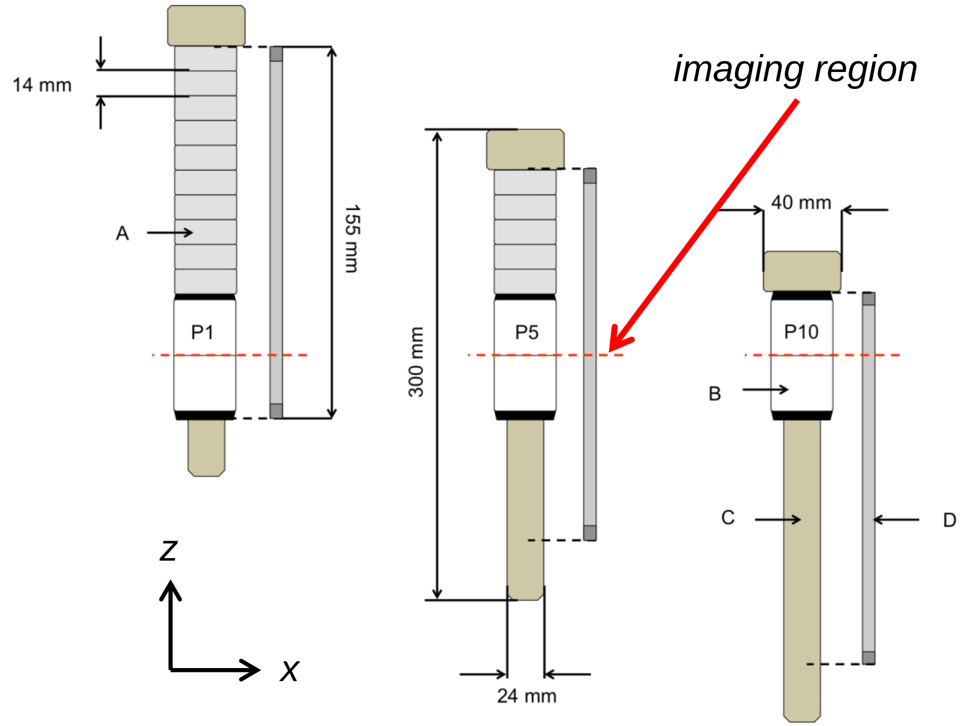


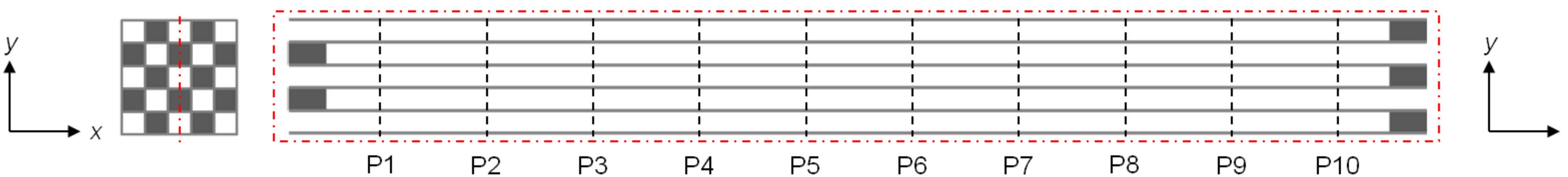
3. Sederman et al. (2007) Catal. Today, 128 (1-2) 3-12
4. Tayler et al. (2012) Phys. Rev. Lett. 108, 264505

Experimental set-up



A – spacer
B – NMR detector
C – flow cell/sample holder
D – DPF substrate





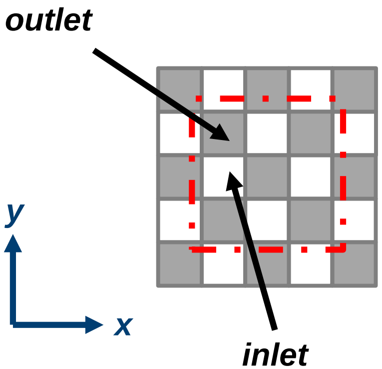
Experimental details

- 10 images of the axial velocity (v_z) in the transverse (xy) plane were acquired
- Sulphur hexafluoride (SF_6) has been used as the NMR active gas
  - *$P = 5 \pm 0.1$ barg and $T = 293 \pm 5$ K; $\rho = 35$ kg m^{-3}, $\mu = 15 \times 10^{-6}$ Pa.s*
- Three flow conditions have been studies: Re = 106, 254, 426

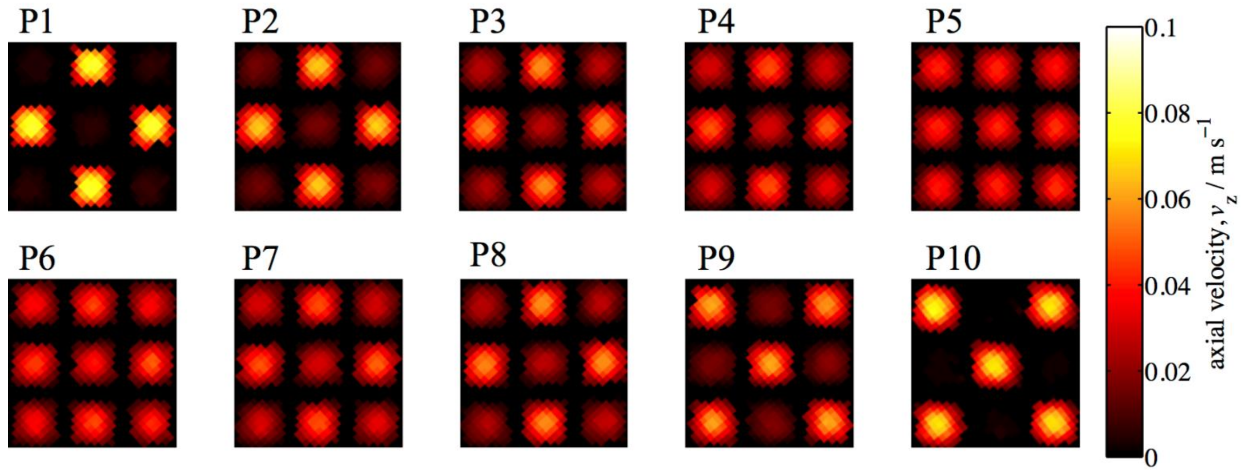
Filter substrate properties	
Material	SiC
Channel length/width	155 mm/1 mm
Cell density	300 cpsi
Porosity	52 ± 4 %
Mean pore size	23 ± 5 μm

MRI parameters	
Field of view	18 mm × 18 mm
Data matrix	128 pixels × 128 pixels
Resolution	0.14 mm $pixel^{-1}$
Slice thickness	12 mm
Acquisition time	14 minutes

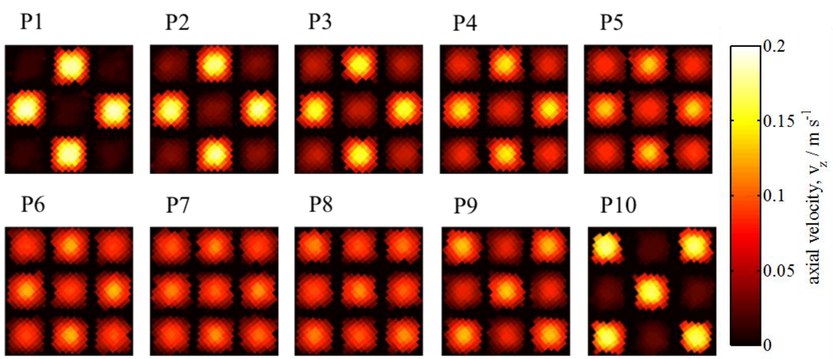
MRI axial velocity (v_z) maps of gas flow in a DPF



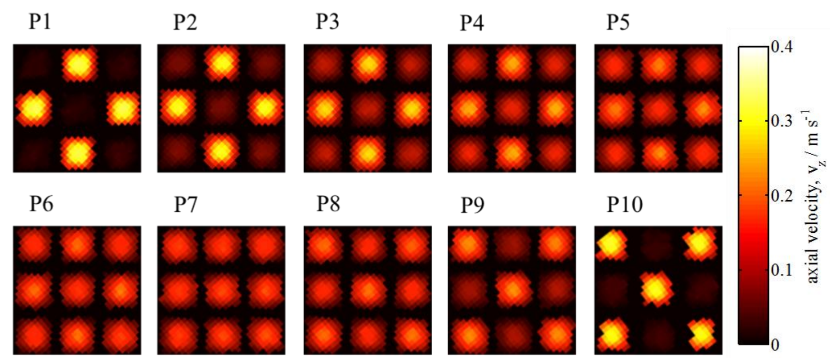
Re = 106



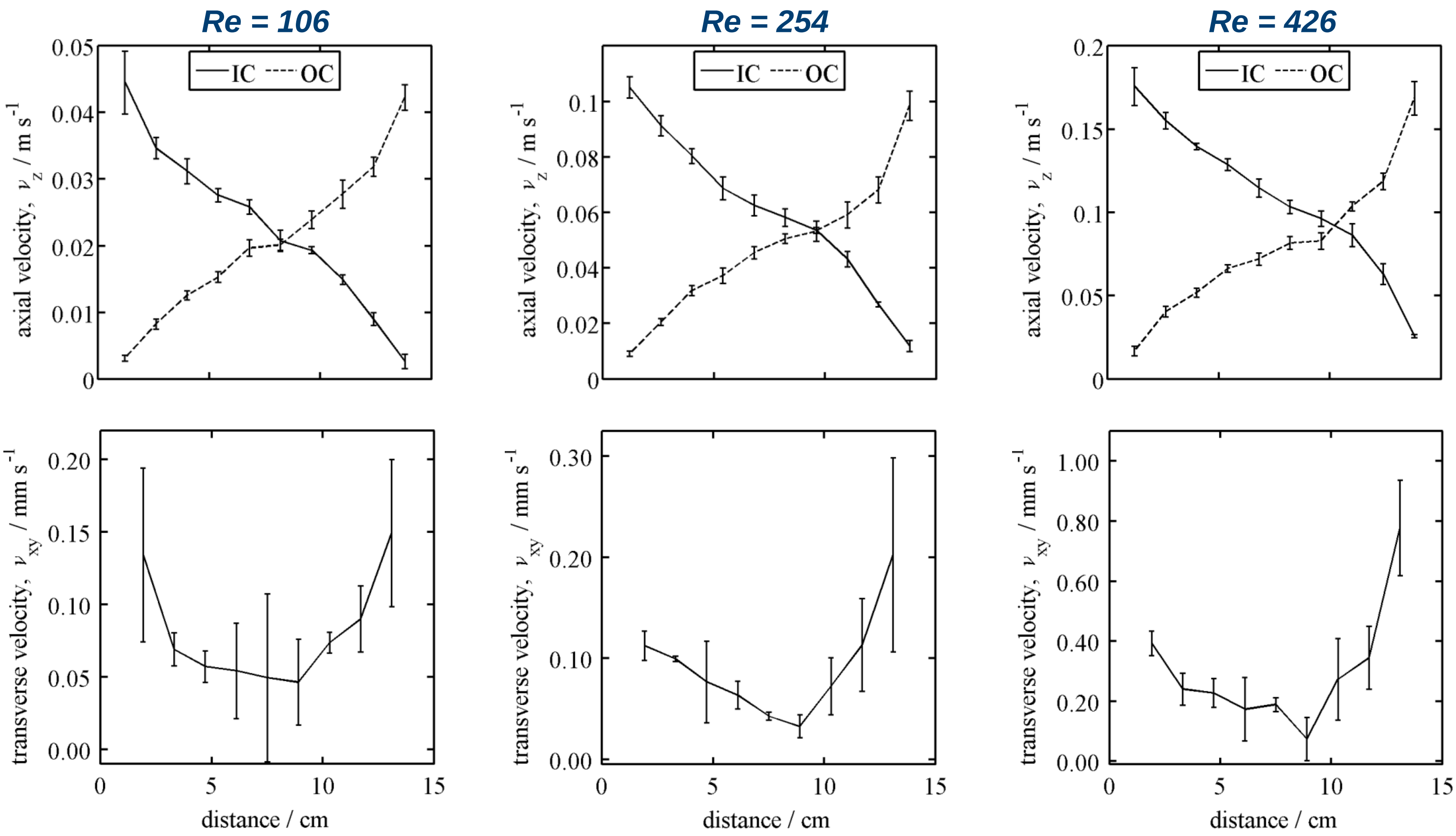
Re = 254



Re = 426



Channel-scale velocity profiles of gas flow in a DPF



Analysis of through-wall flow uniformity

- **It has been shown that the gas flow will influence the PM deposition in the DPF during operation [5]**

- **This in turn will impact the system performance in terms of [6]:**

  - **engine back pressure and therefore fuel efficiency**
  - **filter regeneration**
  - **blocking of catalyst sites (in catalytic systems)**

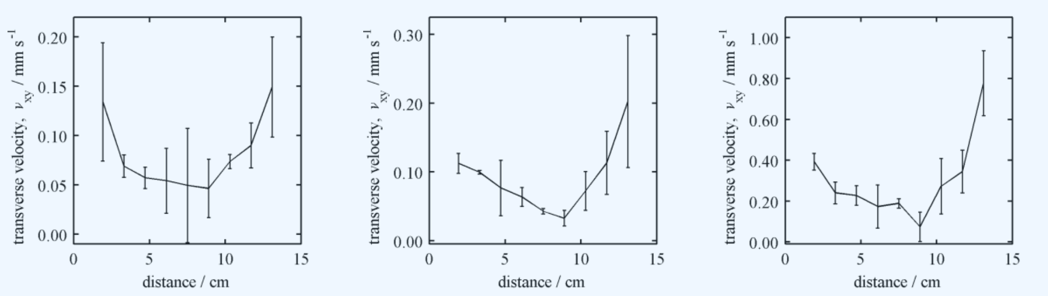
- **PM will follow the stream lines of the gas flow [7]**

- **MRI velocity measurements have been in the analysis of through-wall flow uniformity**

  - **effect of gas flow on the PM deposition profile that would form in a real system**

5. Bensaid et al. (2009), Catal. Today., 147, pp. S295-300
6. Yu et al. (2013) Chem. Eng. J., 22, pp. 68-73
7. Sbrizzai et al. (2005), Chem. Eng. Sci. 60, 23, pp. 6551-6563

Analysis of through-wall flow uniformity

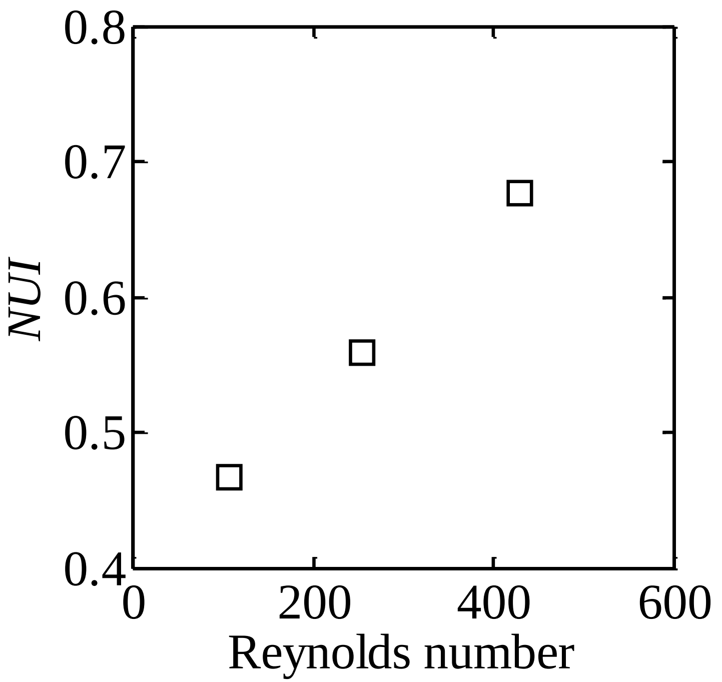


$$NUI = \frac{\sigma_{v_{xy}}}{\mu_{v_{xy}}}$$

NUI ***non-uniformity index*** [5]

$\sigma_{v_{xy}}$ ***standard deviation*** v_{xy}

$\mu_{v_{xy}}$ ***average*** v_{xy}



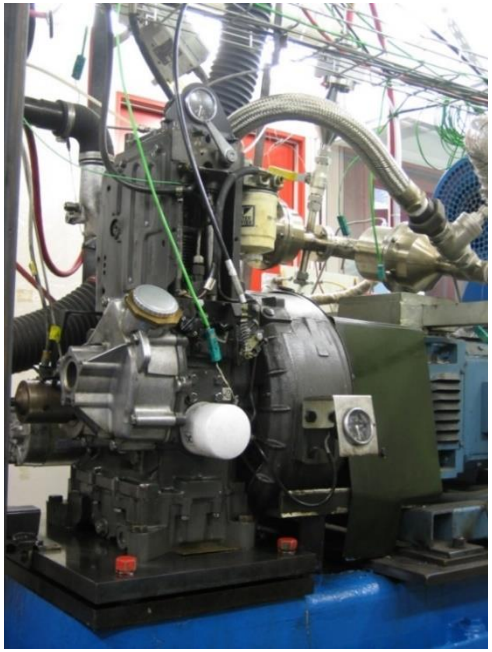
- **The through-wall velocity profile becomes <u>less uniform</u> as the inlet gas flow rate increases**

6. Yu et al. (2013) Chem. Eng. J., 22, pp. 68-73

Effect of soot deposition on the gas flow field

- **Comparison between gas flow in:**
  - **‘clean’ substrate**
  - **soot-loaded substrate**
    - ***90 mins @1500 rpm, 5 bar IMEP, 30% EGR***

- **Measurements were carried out under the same flow conditions (*Re = 100*).**



UNIVERSITY OF BIRMINGHAM

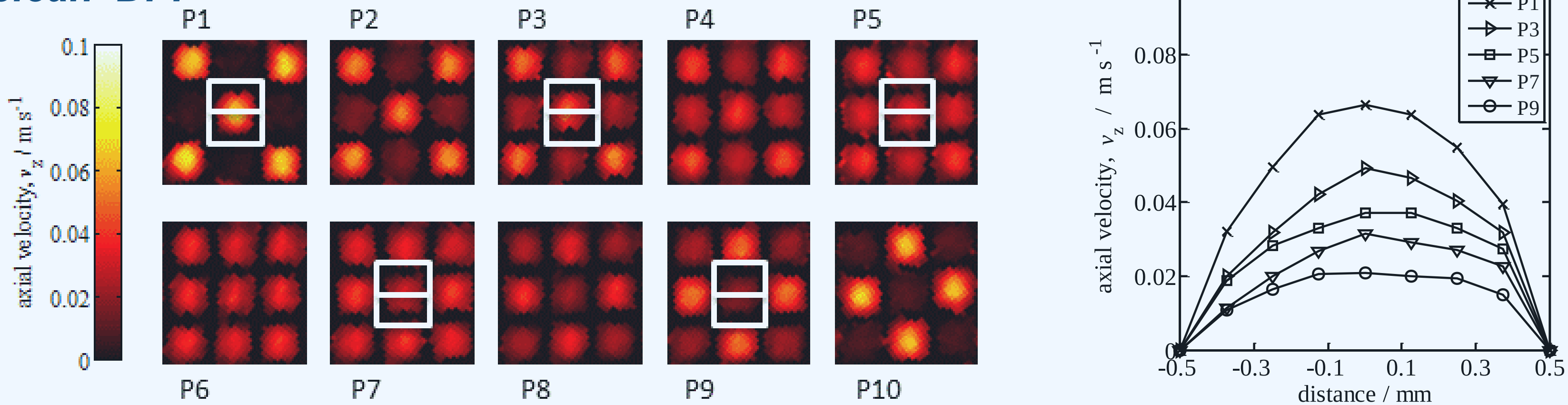
Athanasios Tsolakis
José M. Herreros
Isaline Lefort

Engine: Lister-Petter TR1 **diesel engine**
Bore × stroke: 98.4mm × 101.6 mm
Max. torque: 39.2 Nm @ 1800 rpm
Max. power: 8.6 kW @ 2500 rpm
Compression ratio: 15.5
Fuel: **Ultra-low sulfur diesel**

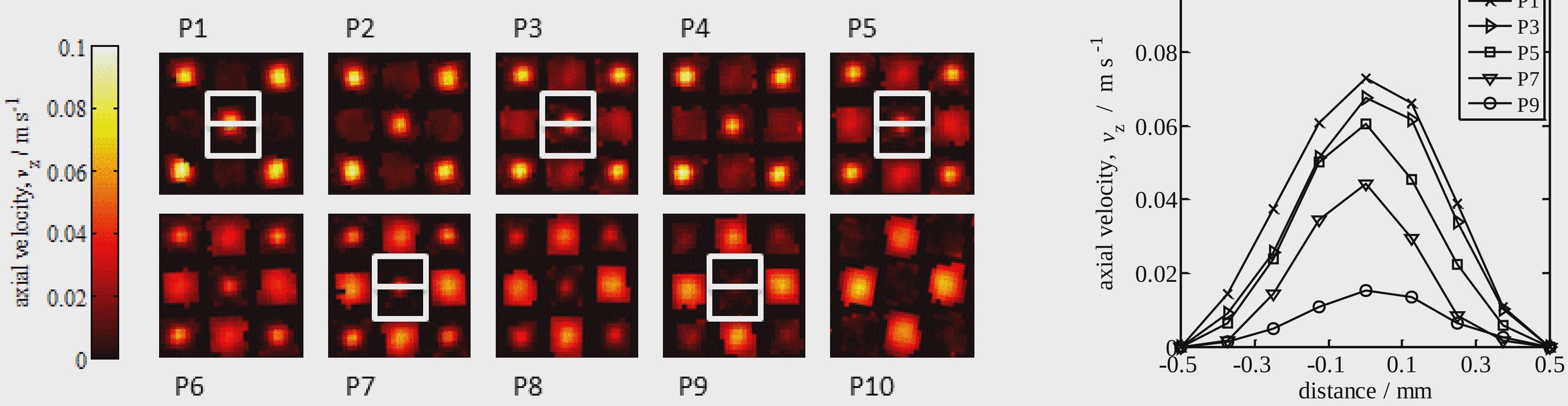
Effect of soot deposition on the gas flow field

MRI axial velocity (v_z) maps of gas flow in a DPF

'clean' DPF



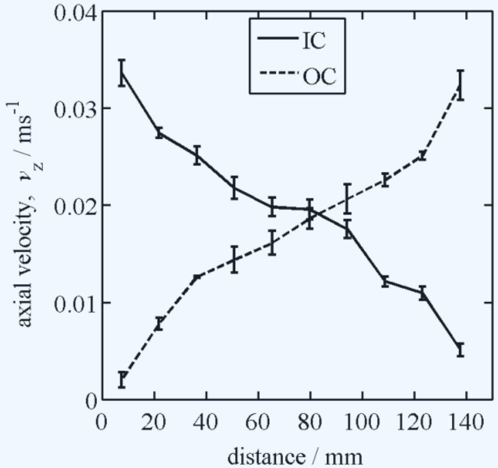
soot-loaded DPF

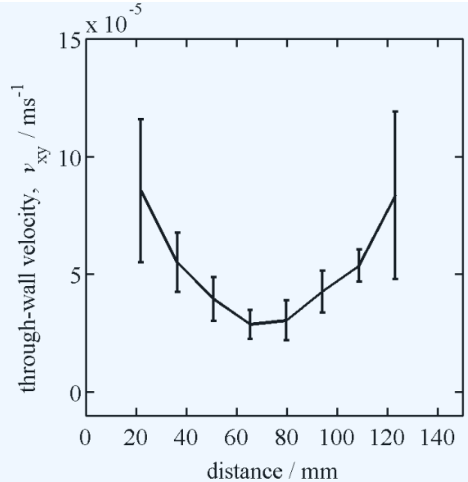


Effect of soot deposition on the gas flow field

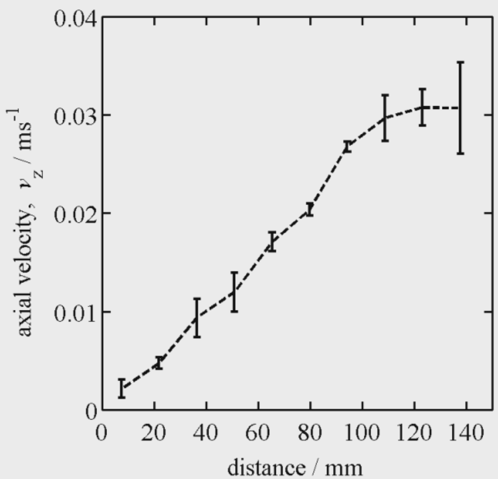
channel-scale velocity profiles of gas flow in a DPF

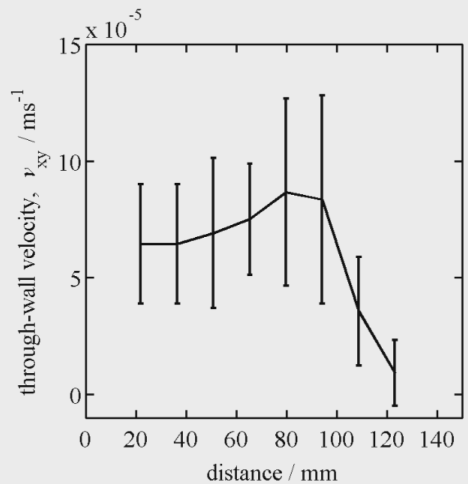
'clean' DPF





soot-loaded DPF





Summary

- MRI velocimetry has been used successfully to study gas flow in a DPF
  - 2D images of the axial velocity along the substrate were acquired
  - channel-scale profiles of the axial and through-wall velocity were obtained
- Data were used to assess how the gas flow may influence PM deposition
- It was observed directly how the PM deposition influences the gas flow field
- There are many other applications of MRI velocimetry
  - effect of catalyst distribution on the gas flow
  - direct validation of computational fluid dynamics (CFD) models

Acknowledgements

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JM Johnson Matthey

EPSRC Engineering and Physical Sciences Research Council


dank u
ju faleminderit
Tack
谢谢
Tak
mulţumesc
Asante
kiitos
Gracias
Salamat!
Terima kasih
Aliquam
Merci
Dankie
Obrigado
ありがとう
köszönöm
grazie
Aliquam
Go raibh maith agat
děkuji
Thank you
gam