

Diesel Particulate Filter design optimization to fulfill the forthcoming BSVII regulation while offering the best overall performance compromise

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■ Heavy Duty EATS : Euro VI to Euro 7

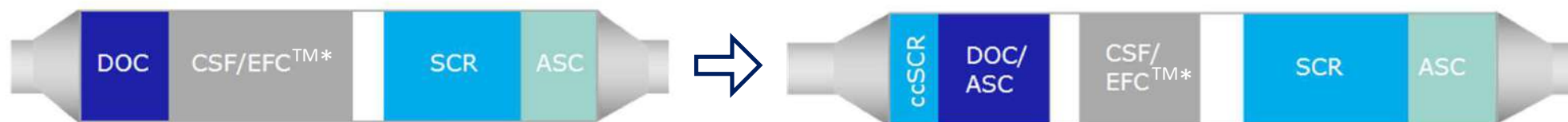


Fig. 2. Schematic of typical Euro VI heavy-duty diesel catalyst system (not to scale)

Source: Johnson Matthey Technol. Rev., 2023, 67, (2), 239–245

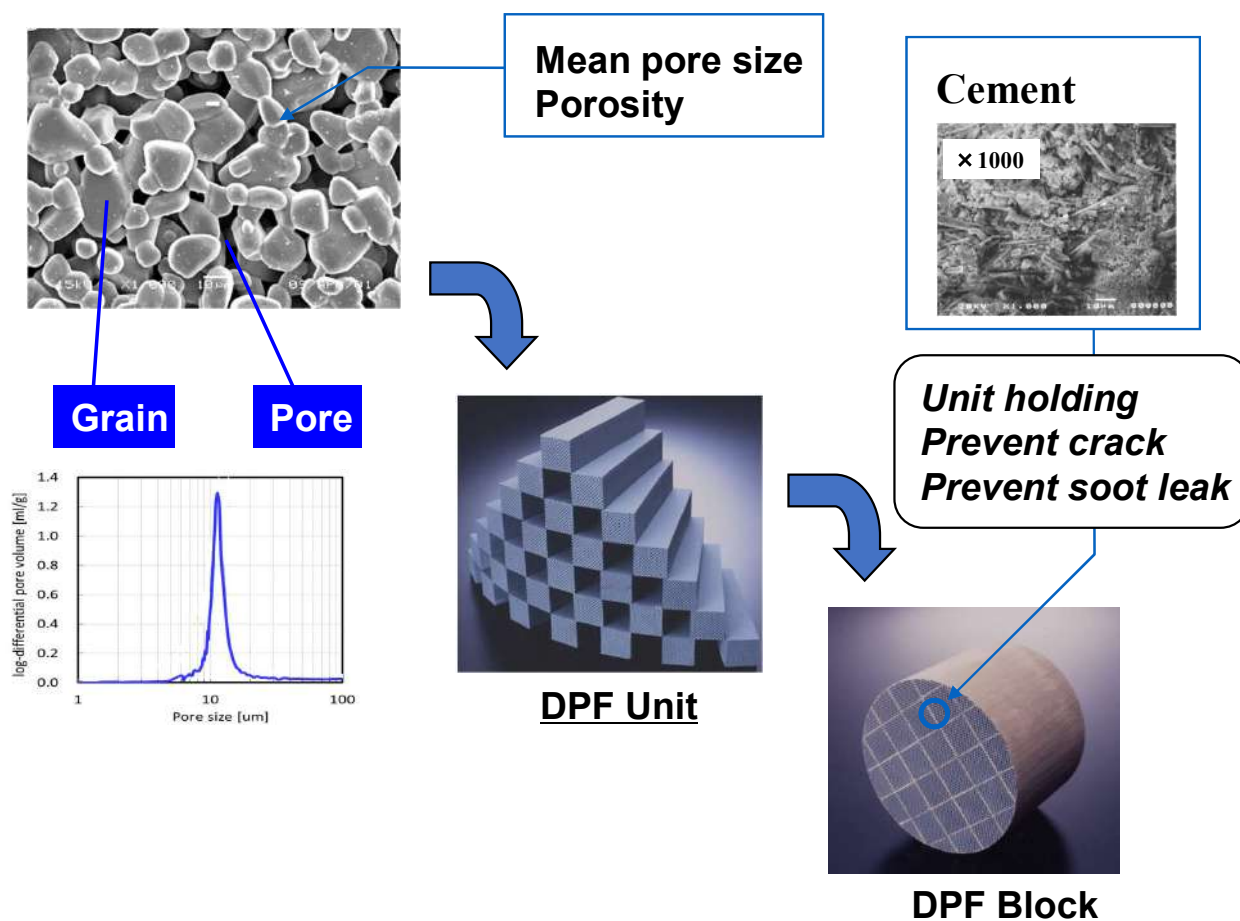
Fig. 5. Schematic of a likely example Euro 7 heavy-duty diesel catalyst system (not to scale)

*EFC™: Enhanced Filtration Coating

Pollutant	EATS technical requirements vs. Euro VI	
	Other than DPF	DPF
PN	- Urea derived particles	- Higher filtration performance
NO _x	<ul style="list-style-type: none"> - Additional SCR brick in C/C position to achieve rapid NO_x conversion light-off at vehicle start-up and in cold operating conditions - Increase U/F SCR volume for higher total NO_x conversion 	<ul style="list-style-type: none"> - Increased total SCR volume => DPF downsizing - Reduced NO₂ inside DPF due to ccSCR negatively affecting overall passive soot RG efficiency => Higher robustness for more frequent soot active RG
CO ₂	- Lower pressure loss	- Lower pressure loss

■ Ividen SiC DPF technology

- Ividen SiC DPF technology is characterized by its sharp pore distribution, high thermal conductivity and segmented structure which all together ensure high filtration performance and robustness.



DPF design		A	B
Filter specification	Cell layout (inlet)		
	Plug layout	Conventional	Valuable Plugging Layout
	Wall thick. [mm]	0.18	0.18
	Cell density [cpsi]	300	300

Fig. Examples of DPF cell designs for HD applications

Ibiden SiC DPF technology – plugging design optimization

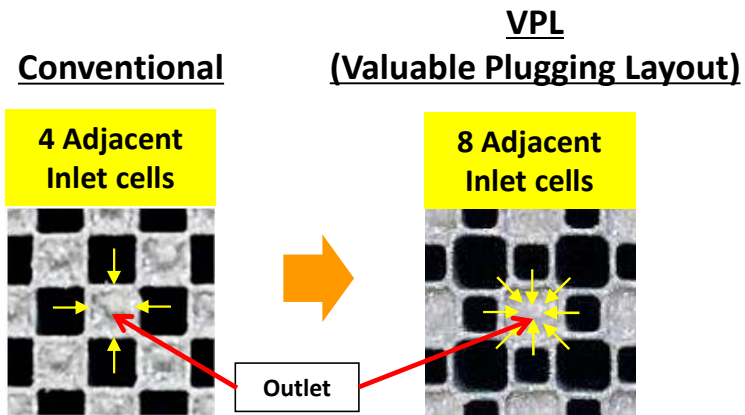


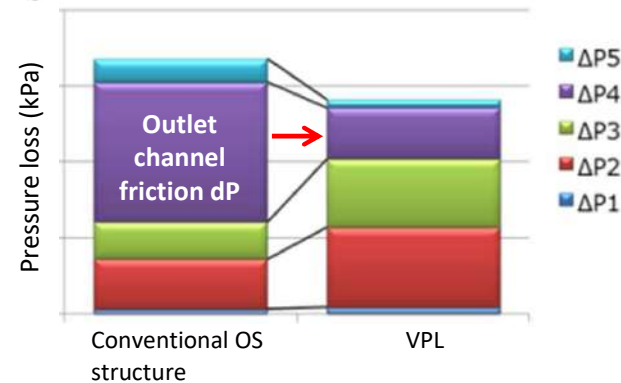
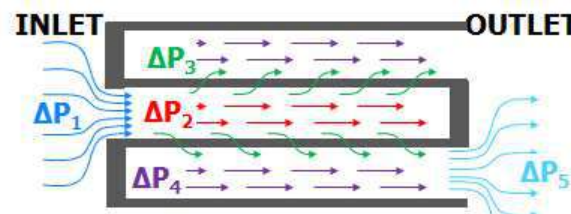
Fig. VPL concept

- **Bigger outlet channels** to reduce friction at outlet channel.
- **Increased # of inlet channels** to increase inlet volume and filtration area

Table 300/7 OFA and filtration area comparison

Plug layout	Normal	VPL
OFA [%]	B.L.	+4%
Filtration Area [cm ² /cm ³]	B.L.	+24%

*Filter diameter 13"



$$\Delta P = \Delta P_1 + \Delta P_2 + \Delta P_3 + \Delta P_4 + \Delta P_5$$

ΔP : Total pressure loss

ΔP₁ : DP from contraction

ΔP₂ : DP from inlet channel friction

ΔP₃ : DP from wall and soot layer

ΔP₄ : DP from outlet channel friction

ΔP₅ : DP from expansion

Fig. Pressure Loss Breakdown

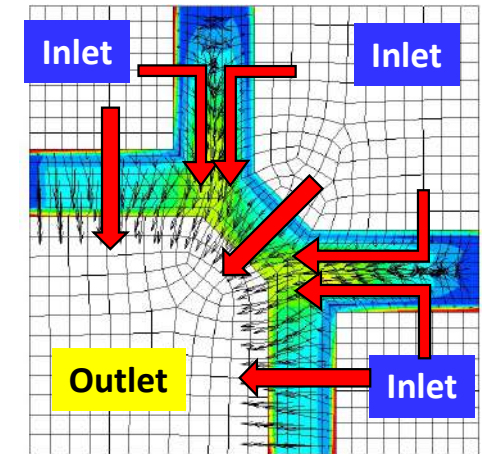


Fig. Gas flow simulation (Soot=4g/L)

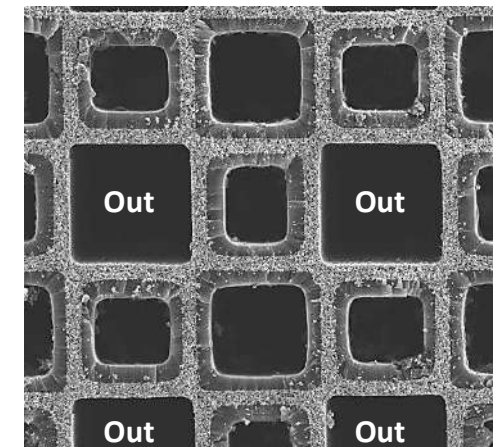
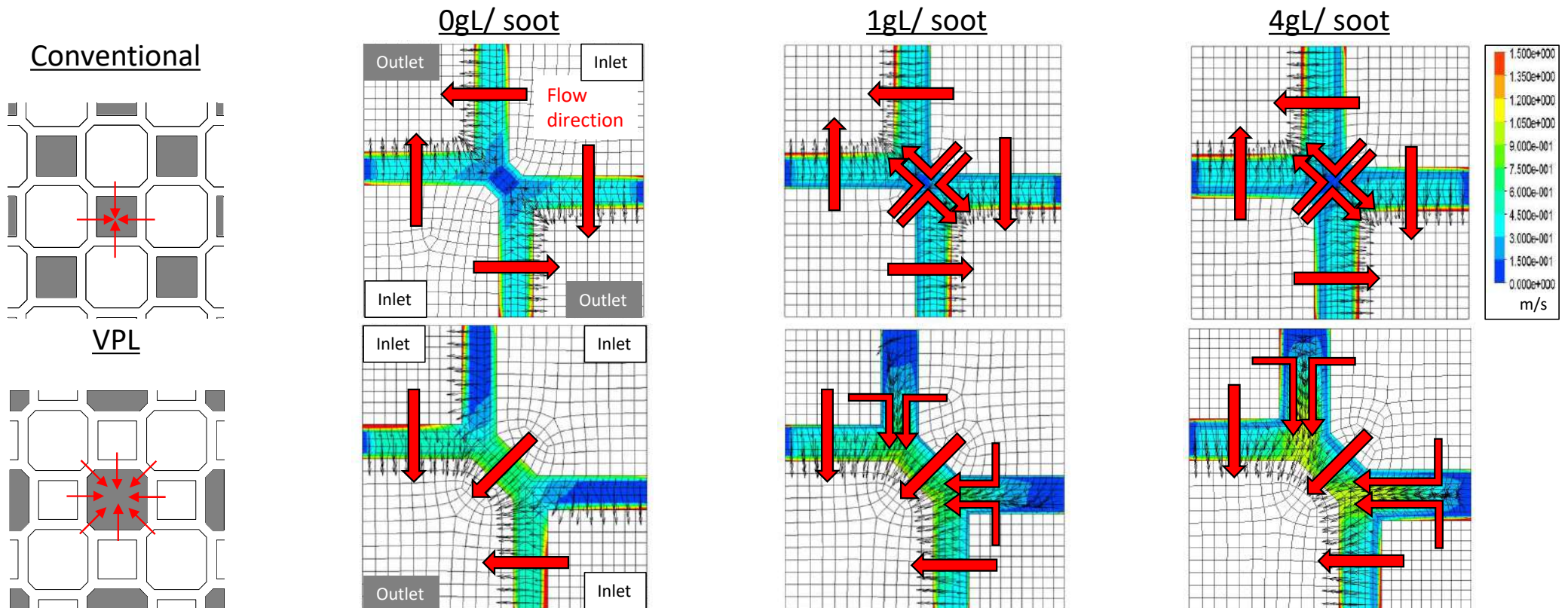


Fig. 300/7 VPL after 10g/L soot loading

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- Flow velocity through DPF walls was calculated for soot loading between 0 and 4g/L. Without soot, gas flow is mainly going through the walls where inlet and outlet channels are adjacent, but as soot cake is building up gas flow deviates to inlet/inlet walls location, which ultimately favors the accumulation of an overall homogeneous soot layer thickness.



■ VPL contribution to EATS design flexibility

- VPL technology reduces DPF pressure loss at life end due to its high total ash capacity and filtration area.
- It provides additional EATS design flexibility, either offering higher compactness or increased specific component performance (like extended ash cleaning interval).

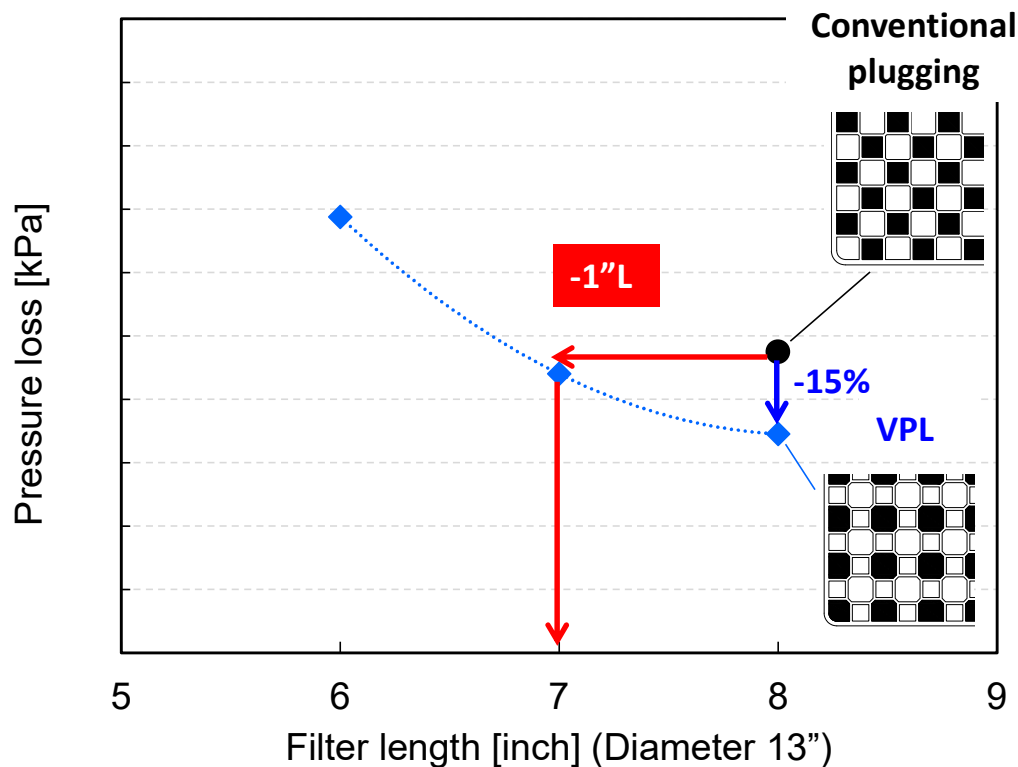
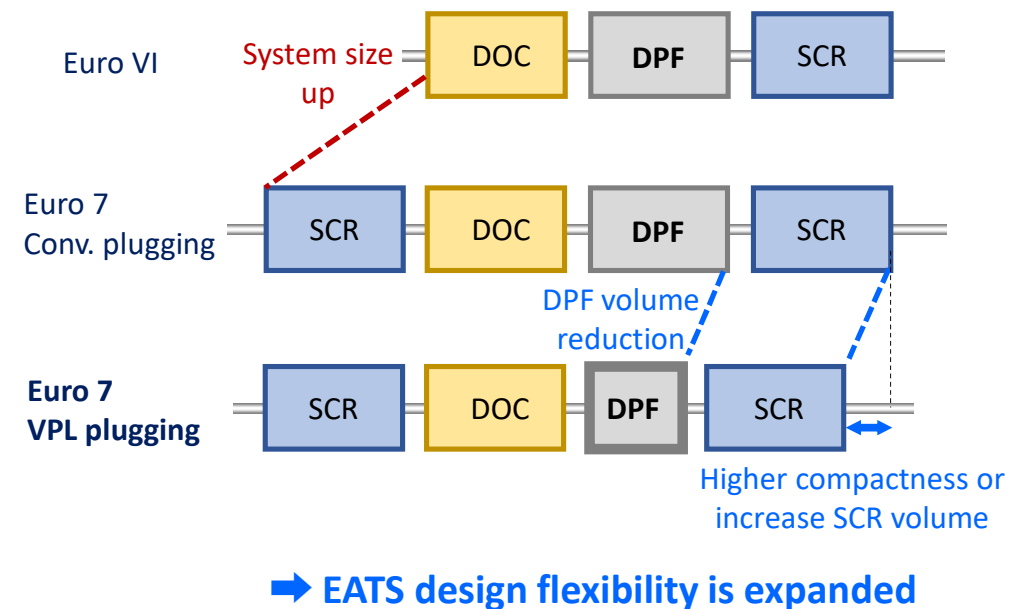


Fig. Pressure loss at end of life condition (soot and ash condition)

■ Effect of DPF volume reduction on soot RG efficiency

- Compact DPF have higher soot regeneration efficiency when exhaust temp. around 250°C.

Table Test sample level

Plugging	Conventional	VPL	VPL
Filter length	9"	9"	7.5"
Cell structure	300cpsi/7mil		
Filter dia.	12"		
Catalyst	Coated		
Soot load	39g/filter		
Ash type	Artificial (powder) accumulated by suction flow		
Ash amount	1600cc volume (470g/filter)		

Table ISC cycles

	ISC1	ISC2	ISC3
Average exhaust temp.	225° C	250° C	270° C

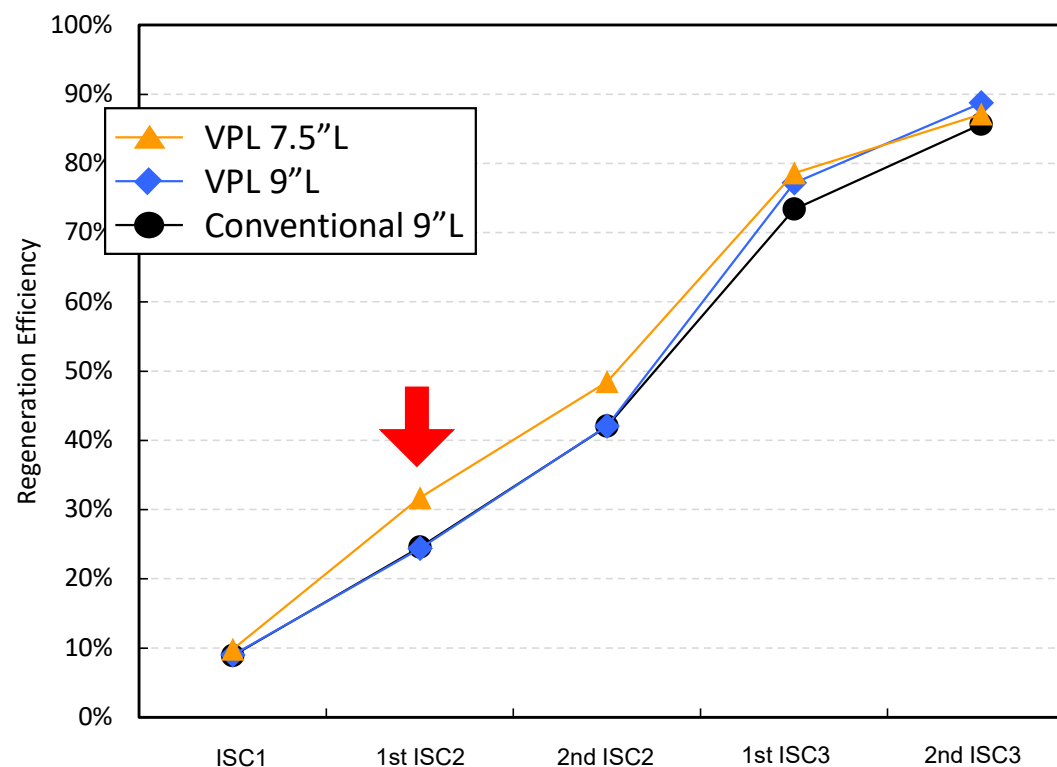


Fig. RG efficiency during RDE testing

Effect of DPF volume reduction on soot RG efficiency

- Due to the combination of thicker soot cake and lower heat capacity (due to its shorter length), compact DPF exhibits higher internal temperatures thus higher soot passive regeneration efficiency during 1st ISC2.

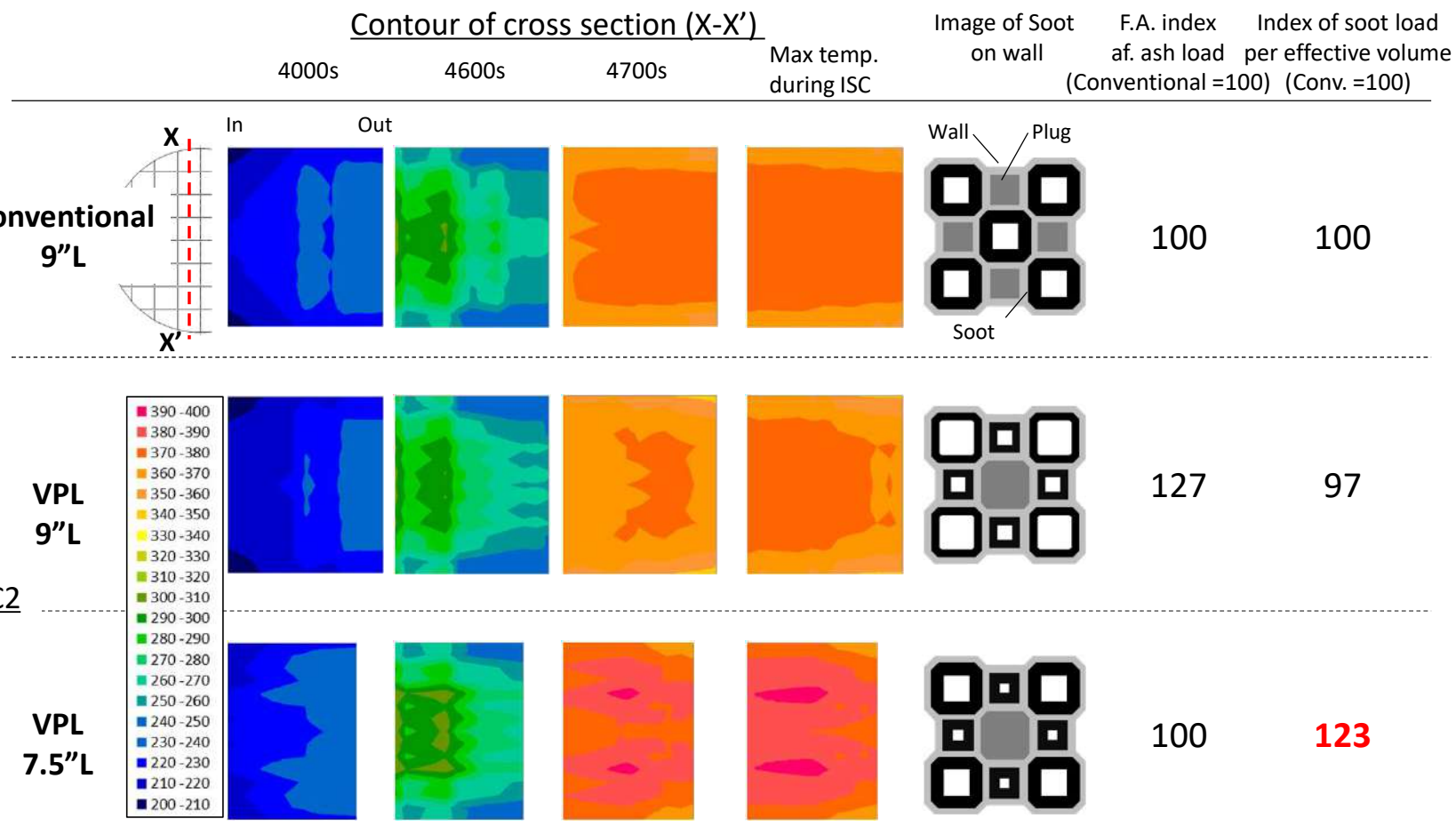
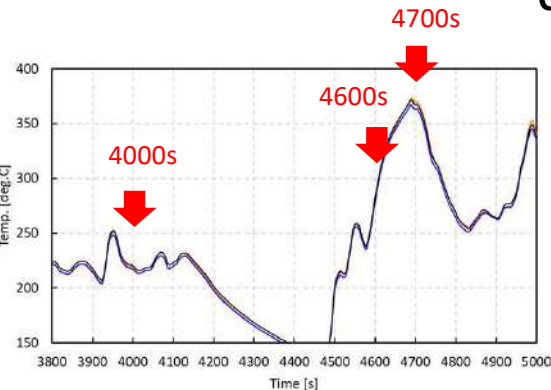


Fig. Inlet gas temp. chart during 1st ISC2

■ Further cell design optimization attempt

- Thicker wall adjacent to outlet channel is considered in order to have more homogenous wall flow velocity.
- It is expected homogeneous wall flow velocity will favor faster even soot cake thickness build-up, thus increase overall filtration performance.

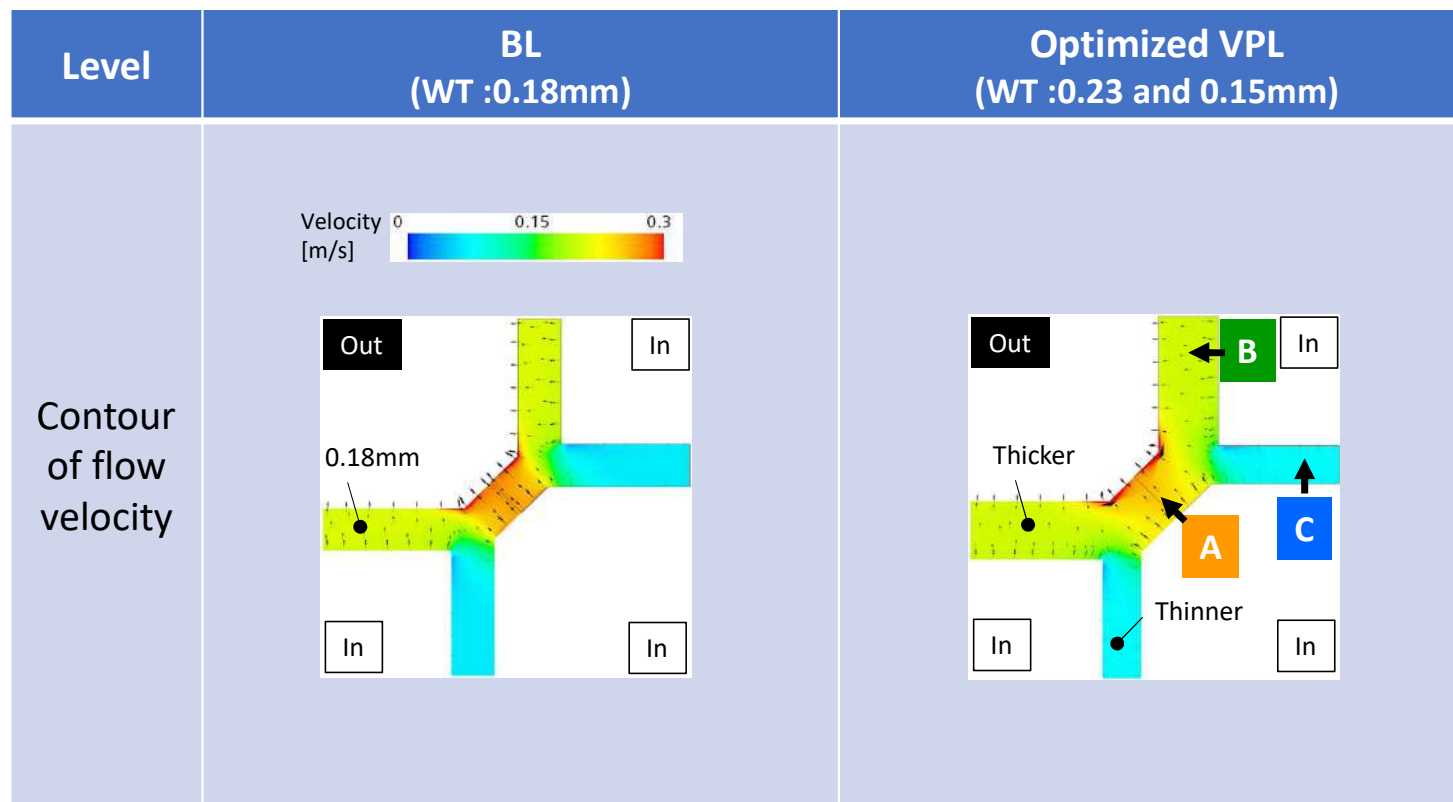


Fig. Flow velocity at each position

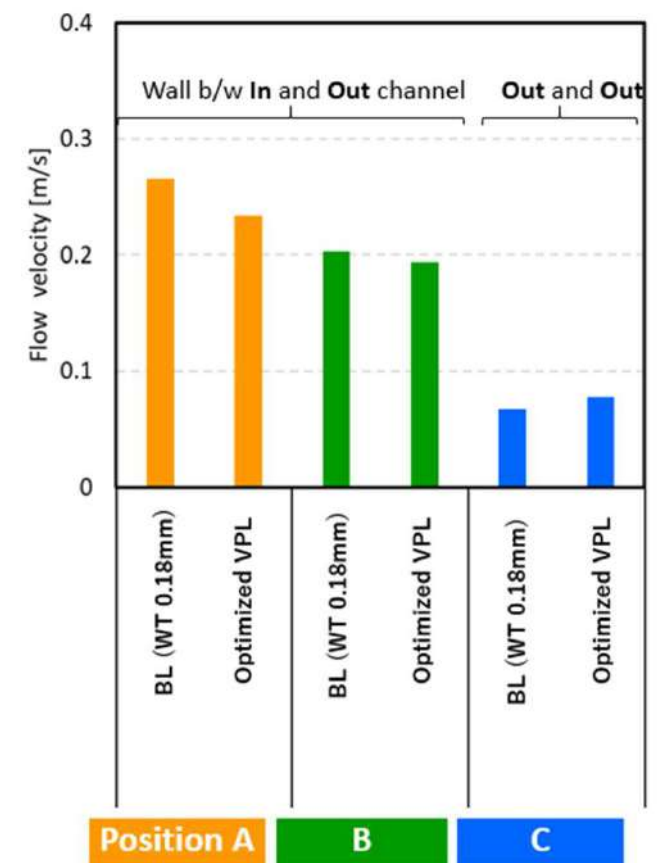


Fig. Flow velocity simulation result

■ Further cell design optimization attempt

- Soot thickness on wall adjacent to outlet cell (A and B) became thicker and thickness at C location became thinner as expected, however, the effect was limited, not supporting further development consideration.

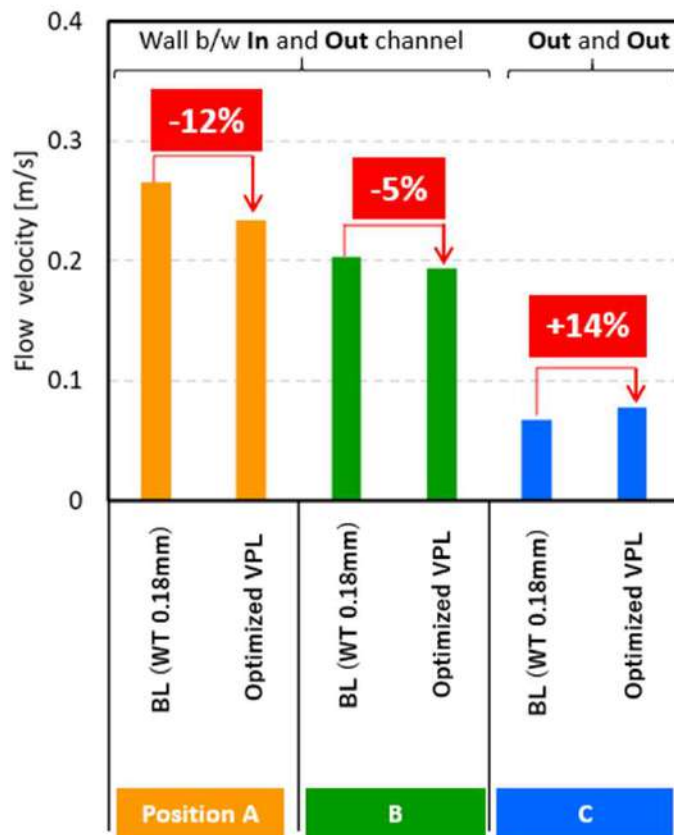


Fig. Flow velocity simulation result

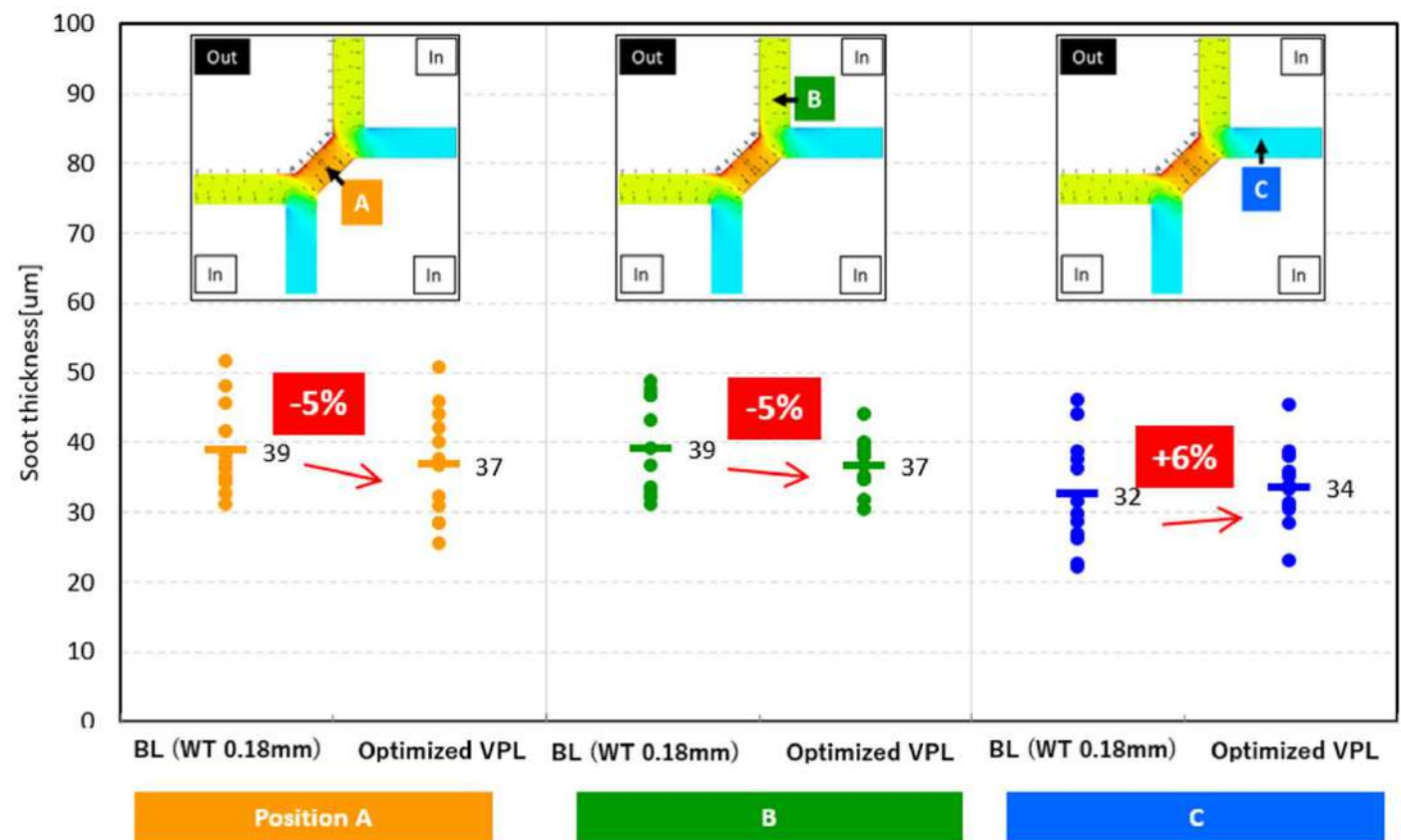


Fig. Soot layer thickness measurement result at each position

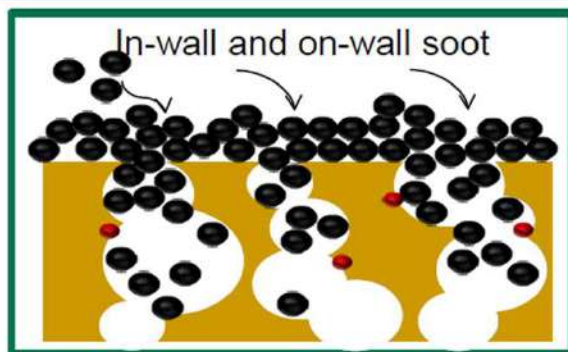
■ Factors influencing PN leakage during Euro 7 RDE testing

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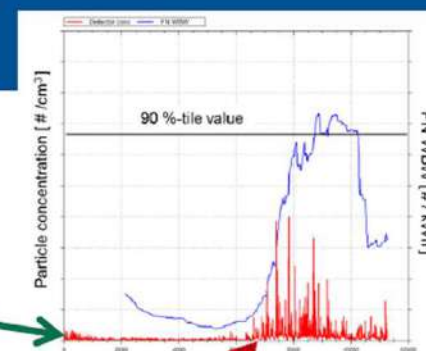
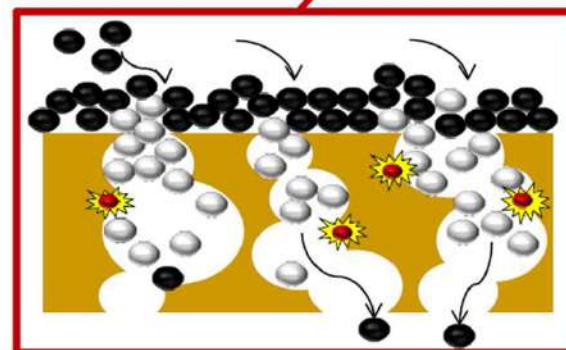


- Passive RG occurring on soot loaded DPF is one potential worst case PN leakage phenomenon which needs to be tackled during Euro 7 RDE testing.

Mechanism – Soot loaded



- When passive regeneration sets in, significant portion of the on-wall soot cake remains, which limits soot feed into filter wall, and thus prevents in-wall soot to replenish
- Some soot pass through soot cake, but either passes through filter or burns



■ Factors influencing PN leakage during Euro 7 RDE testing

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- Highest PN emission systematically occurs during 1st ISC3 when thin soot cake remains on-wall.
- WBW PN emission increases together with bare substrate pore diameter – Reduced by 70% with Euro 7 advanced coating.

Table RDE test condition

Item	Content
Cell structure	OS1.0
Plug layout	VPL
Cell density	300cpsi
Wall thickness	0.18mm
Filter size	D13"x7"L
EATS	DOC + DPF – no urea injection
Test condition	ISC1-2-3
PN counter	>10nm counter

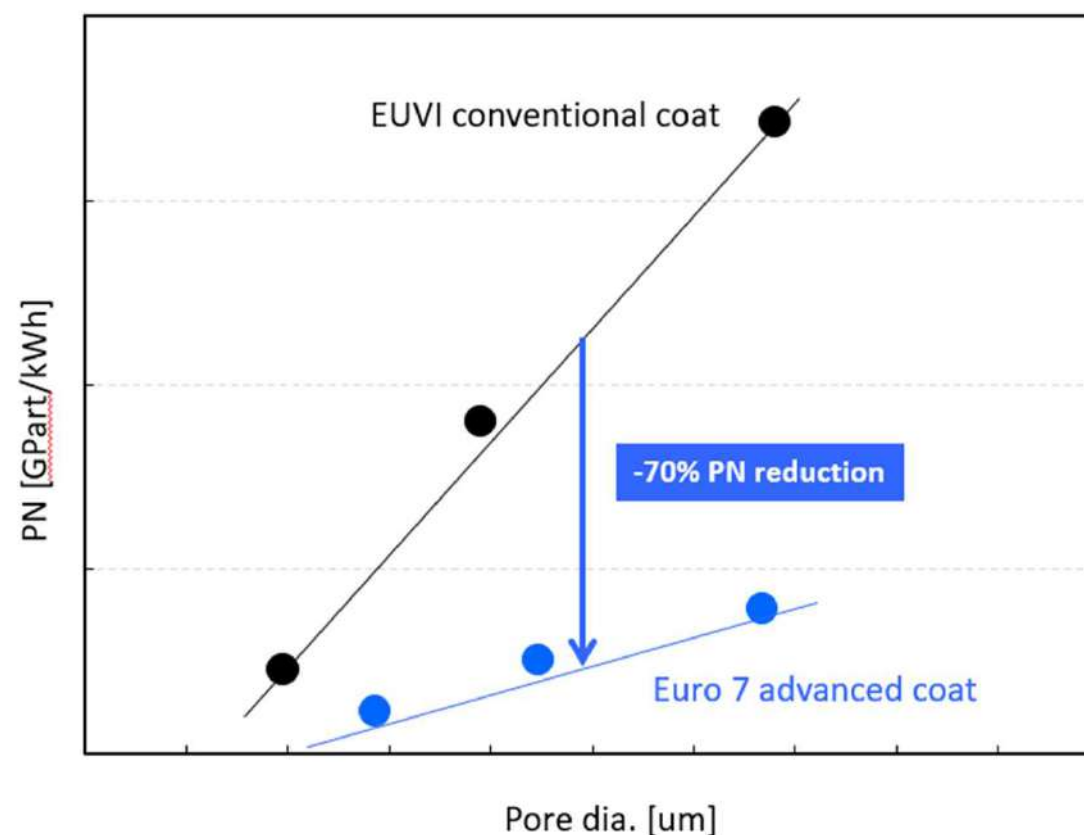


Fig. PN emission over pore size

Factors influencing PN leakage during Euro 7 RDE testing

- Cell plug design has no influence on the extent of max WBW PN emission during RDE testing.
- OS ratio has marginal effect, increasing wall thickness positively affects filtration performance.

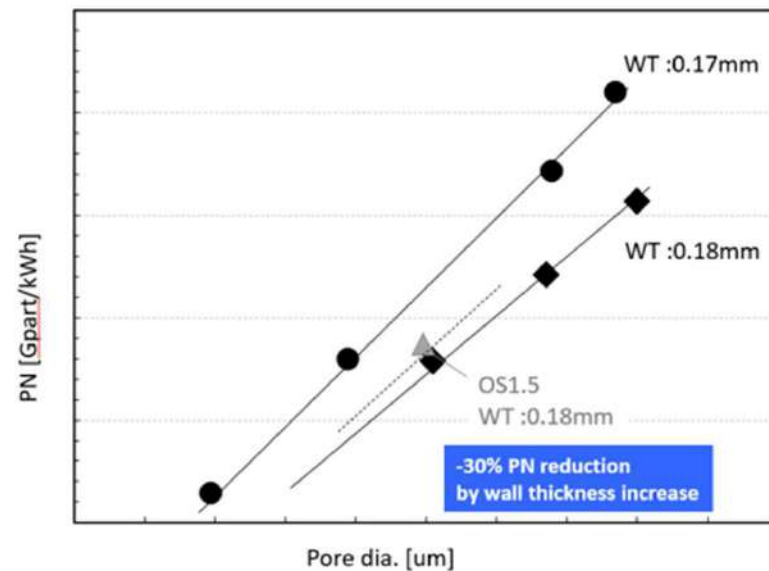


Fig. PN emission over pore size

Influence of
cell design

Influence of
cell plug type

Cell layout (inlet)	
Cell structure	OS1.0
Plug layout	VPL
Wall thick. [mm]	0.18
Cell density [cpsi]	300
Filter size	D13"x7"L

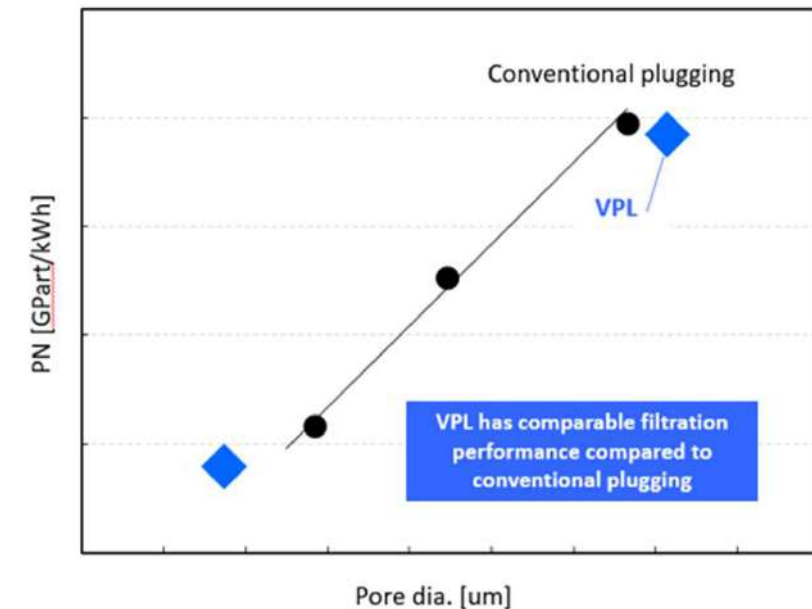


Fig. PN emission over pore size

- More stringent tailpipe emission limits will be introduced with Euro 7, requiring a global optimization of EATS architecture.
- Specific RDE limits, reduced particulate measurement size and the lowering of minimum power threshold will overall require significant improvement of DPF PN filtration performance.
- Through DPF cell design optimization (wall thickness, pore diameter etc) and its combination with advanced coating it was confirmed Euro 7 PN emission limit could be fulfilled, even in the most stringent testing conditions (start-up, soot passive RG during RDE testing etc).
- Ividen optimized plugging design (VPL) allows for DPF downsizing, providing additional EATS design flexibility either offering higher compactness or increased specific component performance.

❖ Acknowledgments

Ividen would like to thank **Johnson Matthey plc** for applying the catalyst coatings on DPF substrates.