Performance Evaluation of Three-way Catalyst (TWC) Coated Sintered Metal Fiber Media for Engine After-treatment Application

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Center for Filtration Research

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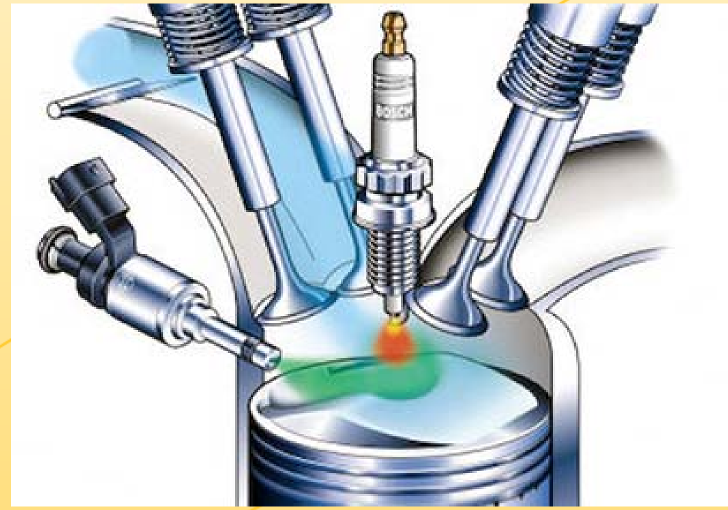
Introduction – GDI engine & PM regulations

- Gasoline direct injection (GDI) engine:
  - Improved fuel economy
  - Less CO_2 emission
  - Lightweighting – smaller engine for same power
- GDI engine leads to higher PM emission:
  - Fuel impingement onto piston surface or cylinder walls
  - Uneven mixing of fuel and air
  - Overfueling during accelerations



	2013	2014	2015	2016	2017	2018	2019	2020	2021…	…2025
	**LEV2** Diesel/Gasoline(DI): PM 10 mg/mile		**LEV3** Diesel/Gasoline(DI): ***PM 6 mg/mile***		**LEV3** Diesel/Gasoline(DI) Phase-In (%): ***PM 3 mg/mile***				**LEV3** All: PM ***3 mg/mile***	**LEV3** All %: PM ***1 mg/mile***
	**Euro5** Diesel: PM 5.0 mg/km Gasoline (DI): PM 5.0 mg/km	**Euro6b** Diesel: PM 4.5 mg/km ***PN 6*10^11 #/km*** Gasoline (DI): PM 4.5 mg/km ***PN 6*10^12 #/km***				**Euro6c** Diesel/Gasoline(DI): PM 4.5 mg/km ***PN 6*10^11 #/km***			**Euro7?**	

(Reproduced from Kattouah *et al.*, 2013)

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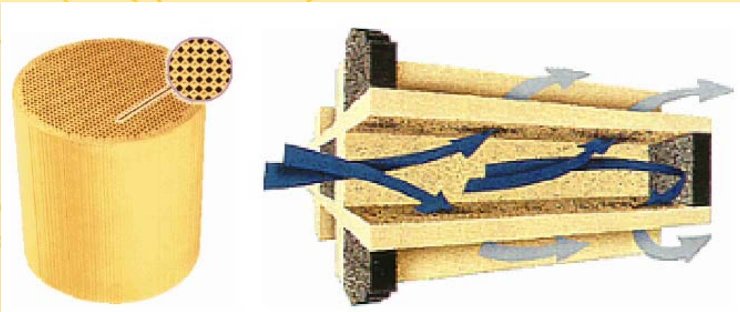
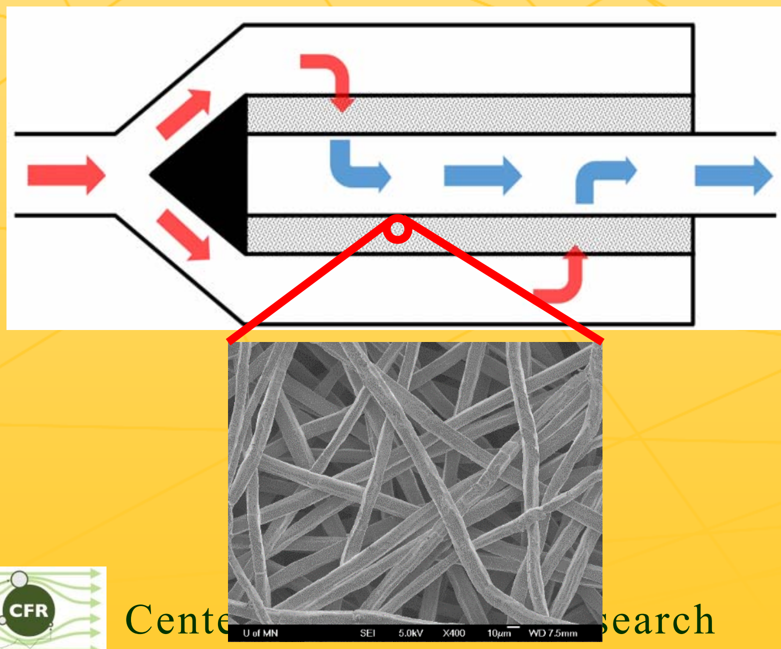
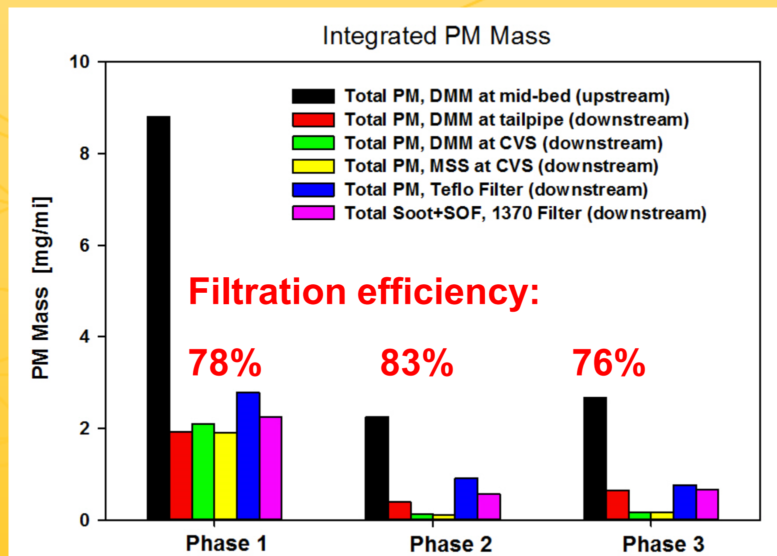
Introduction – metallic GPFs?

- Conventional ceramic wall flow filters used for diesel particulate filter (DPF) has a suboptimal tradeoff between filtration efficiency and backpressure.



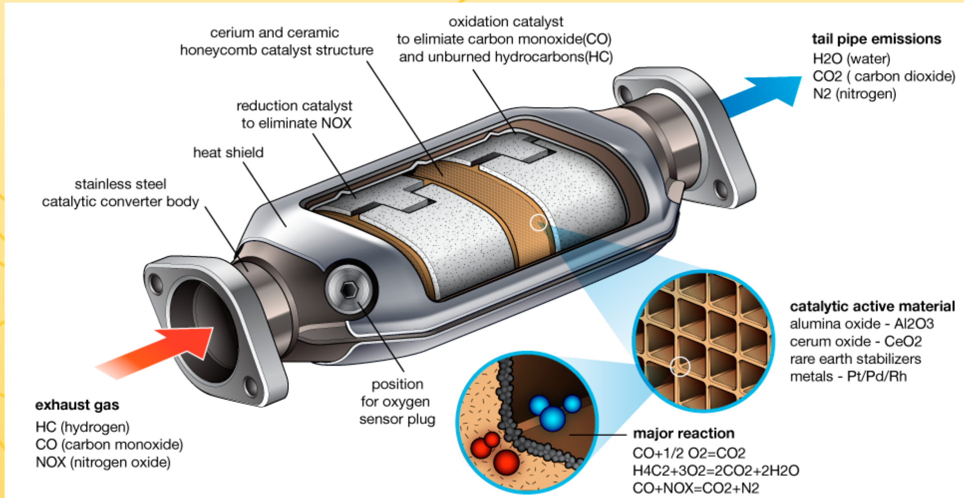
- **Metallic** Gasoline Particulate Filter (GPF) prototype manufactured by Shengda Filtration Technique Co., LTD shows good filtration efficiency and low backpressure.





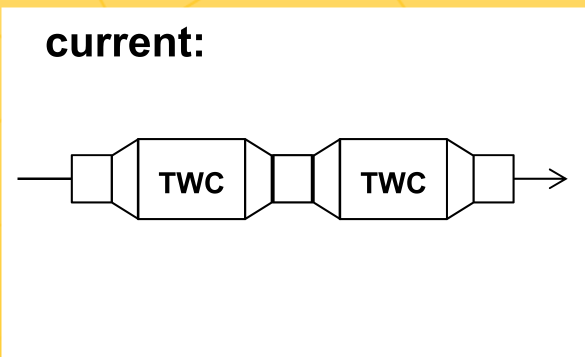
Introduction – TWC converters

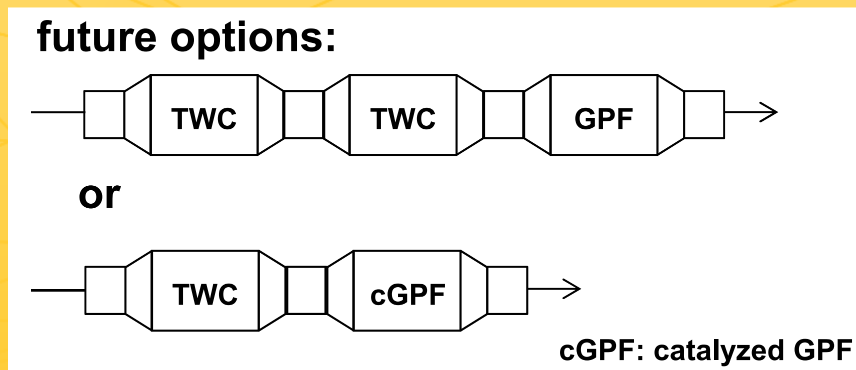
- **Three-way catalytic converters** (TWC) have been widely used in vehicle emission control systems for decades, to convert carbon monoxide (CO), unburned hydrocarbon (HC), and oxides of nitrogen (NOx).



(http://images.cars.com/original/srvc-gloss/1415725879171.png)

- TWC converter can be potentially combined with a GPF, to reduce the space, cost, and backpressure of an exhaust after-treatment system.





Metal fiber media samples

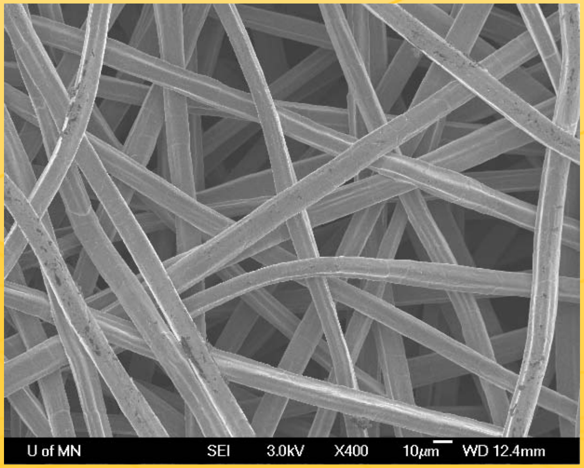
Media #	Fiber diameter [µm]	Porosity [--]	Thickness [mm]	Wash-coating loading* [g/in^3]				
				Method A			Method B	Method C
				Level 1	Level 2	Level 3	Level 1	Level 1
1	12	0.8	0.8	1.29	2.08	3.66	1.29	1.21
2	12	0.7	0.6	1.40	2.21	3.88	1.46	1.27
3	12	0.7	0.4	1.21	1.90	3.80	1.21	1.13
4	12	0.6	0.3	1.56	2.32	3.99	1.24	1.30
5	8	0.8	0.4	1.46	1.98	4.00	1.25	1.17
6	8	0.7	0.2	1.86	2.10	3.96	1.70	1.21

*: average value of 2 coated samples, details in appendix

Notation:

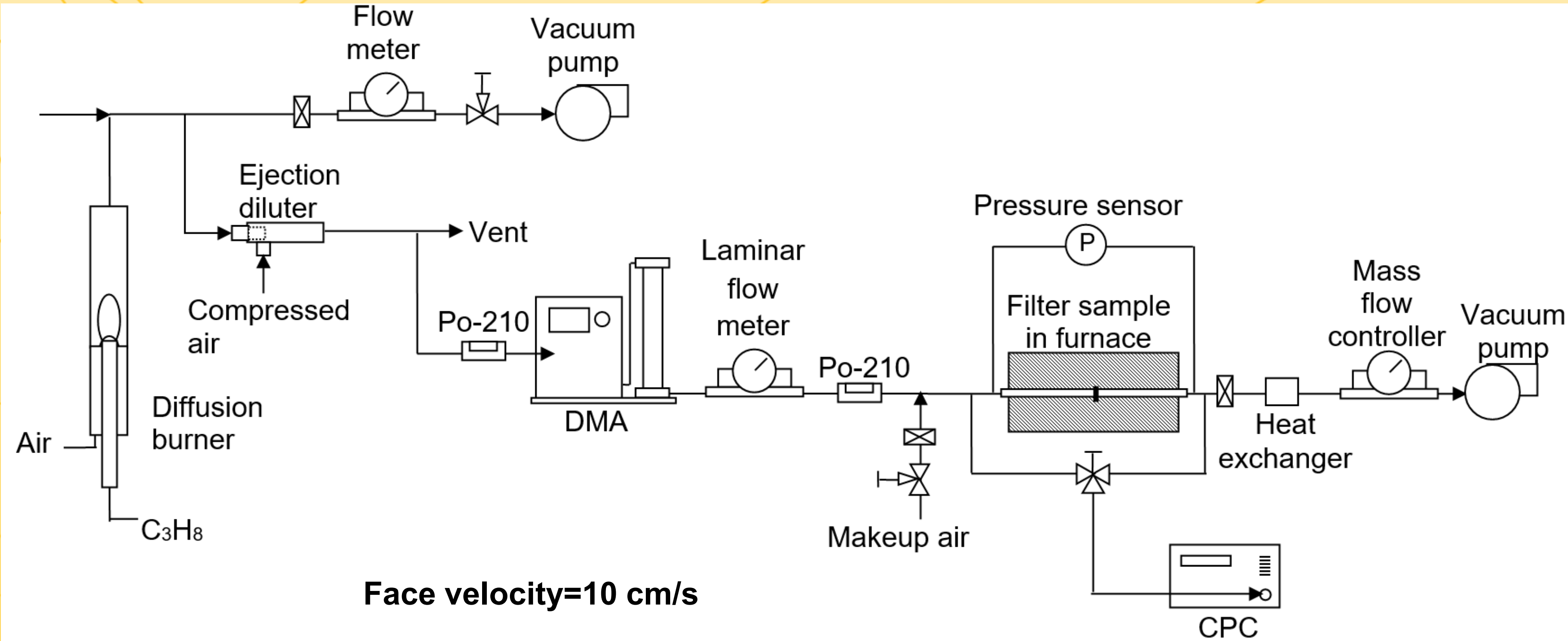
1-2-1A

- **Coating method**
- **Sample #**
- **Coating level**
- **Media #**



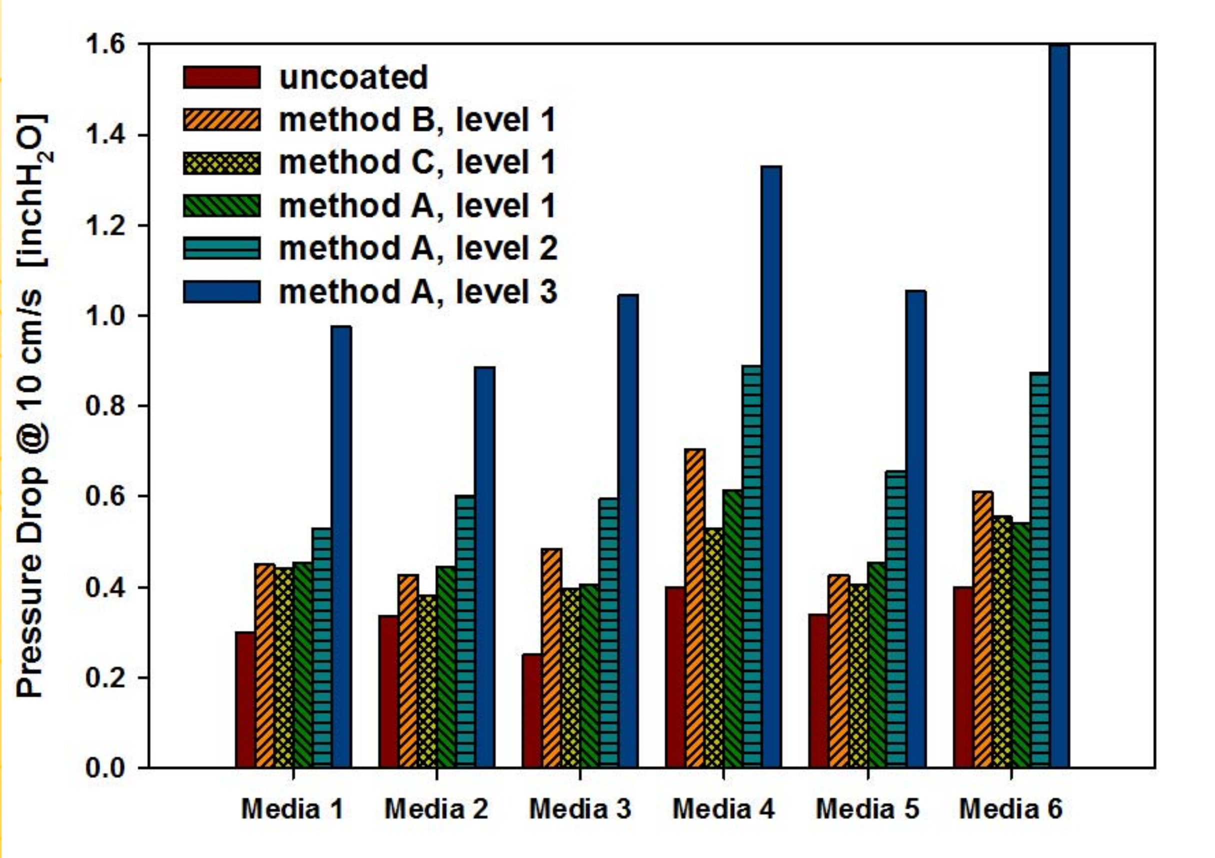
Media 2

Test setup



Flow meter
Vacuum pump
Ejection diluter
Vent
Compressed air
Po-210
DMA
Laminar flow meter
Po-210
Pressure sensor
P
Filter sample in furnace
Mass flow controller
Vacuum pump
Heat exchanger
Makeup air
CPC
Air
Diffusion burner
C_3H_8
Face velocity=10 cm/s

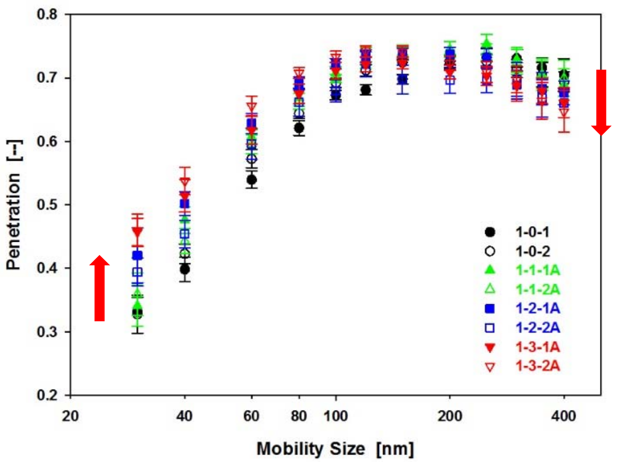
Flow resistance



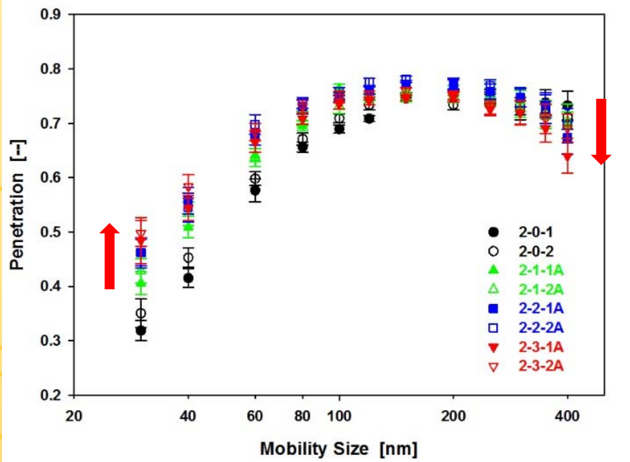
- Flow resistance of coated samples increases with coating levels for all 6 media grades.
- Flow resistance at level 1 among three coating methods (A, B, & C) are close, with largest difference less than 25%.

Soot removal – fractional efficiency (I)

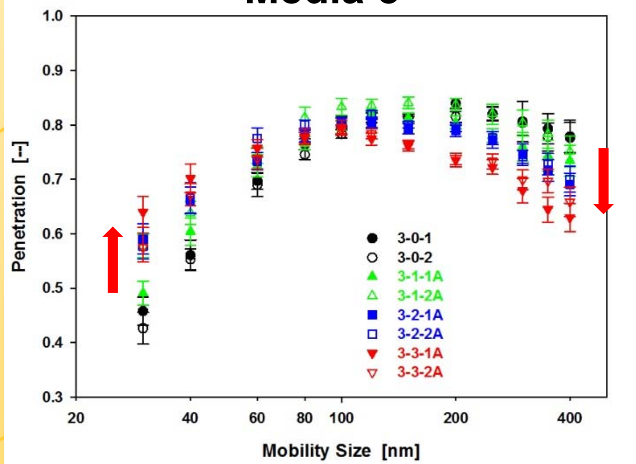
Media 1



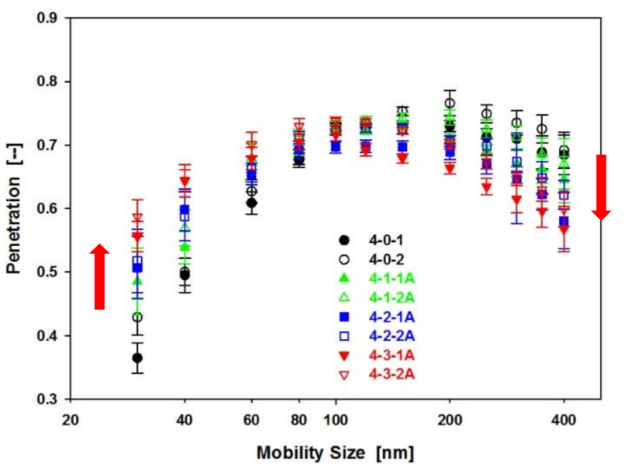
Media 2



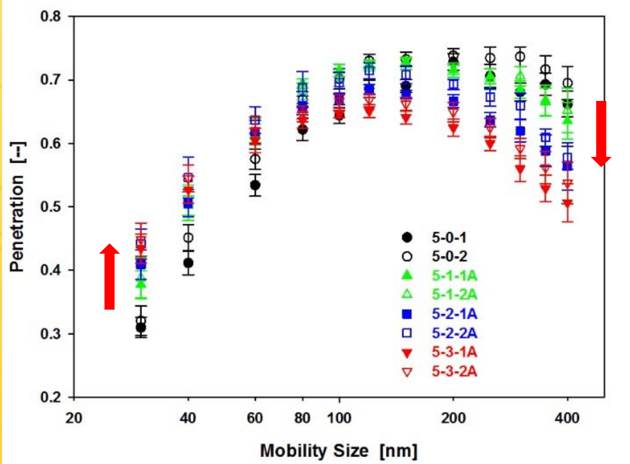
Media 3



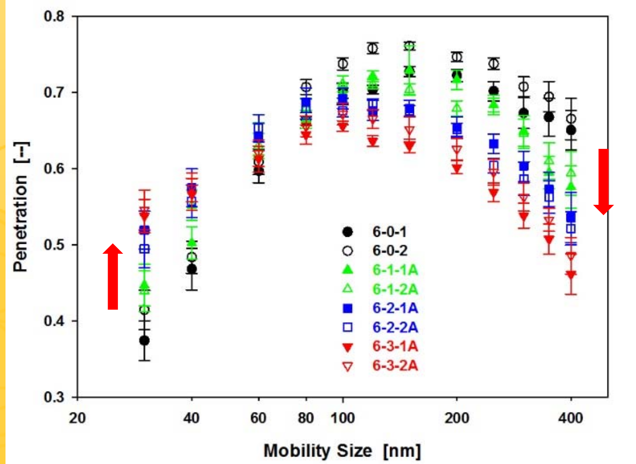
Media 4



Media 5

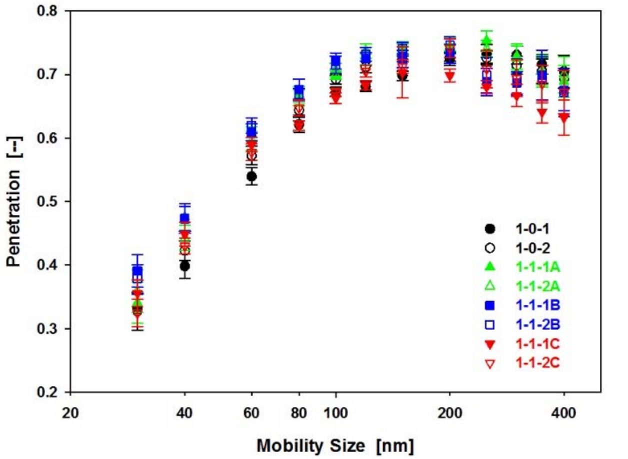


Media 6

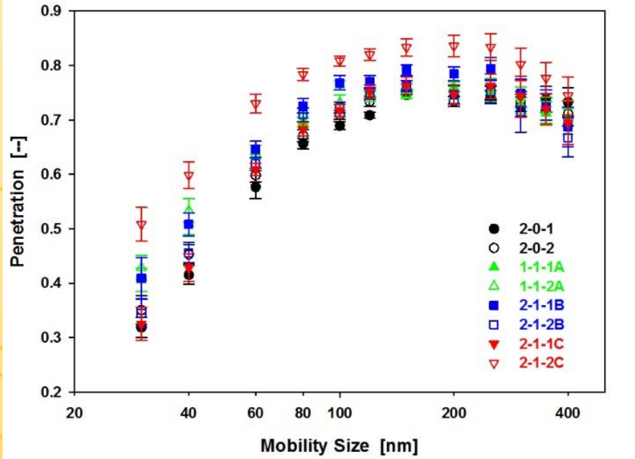


Soot removal – fractional efficiency (II)

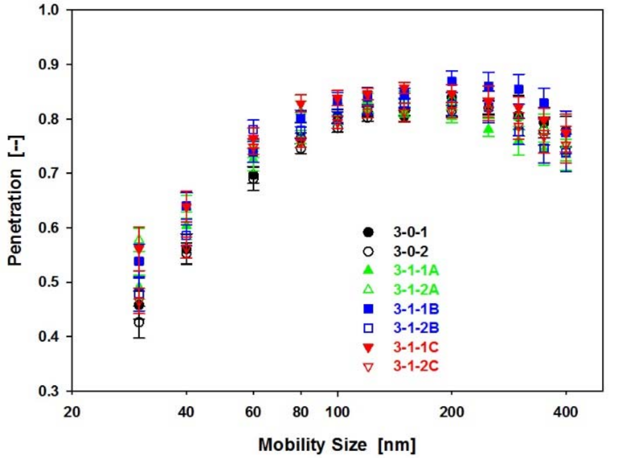
Media 1



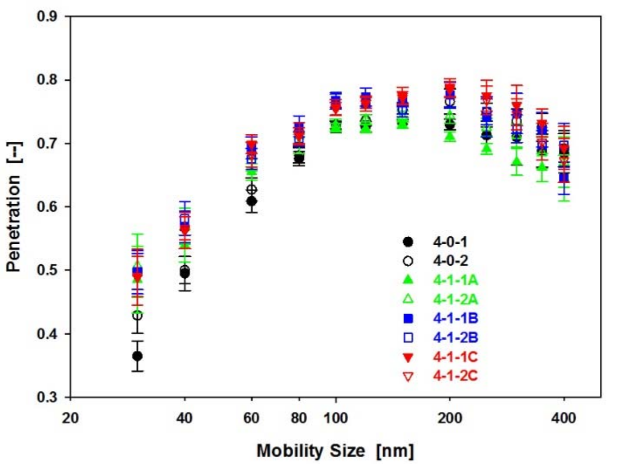
Media 2



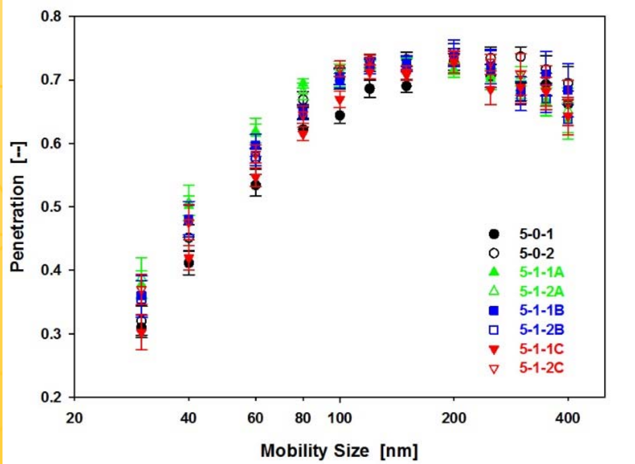
Media 3



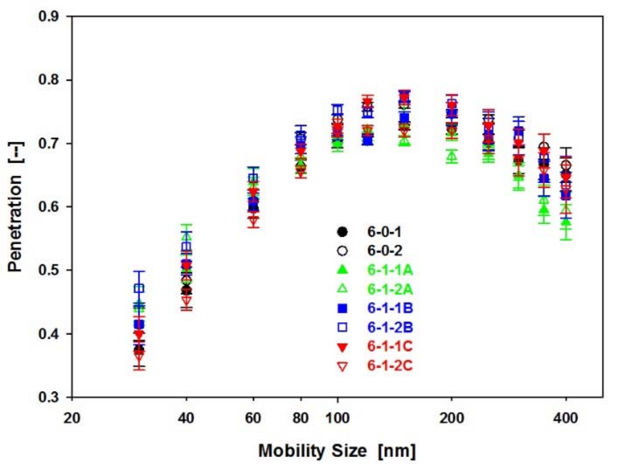
Media 4



Media 5



Media 6

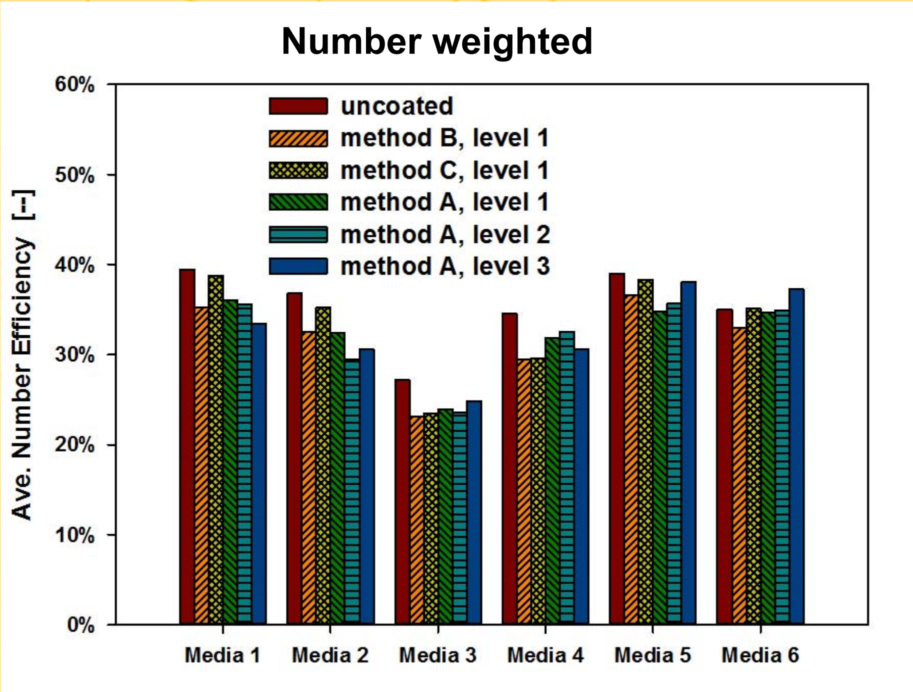


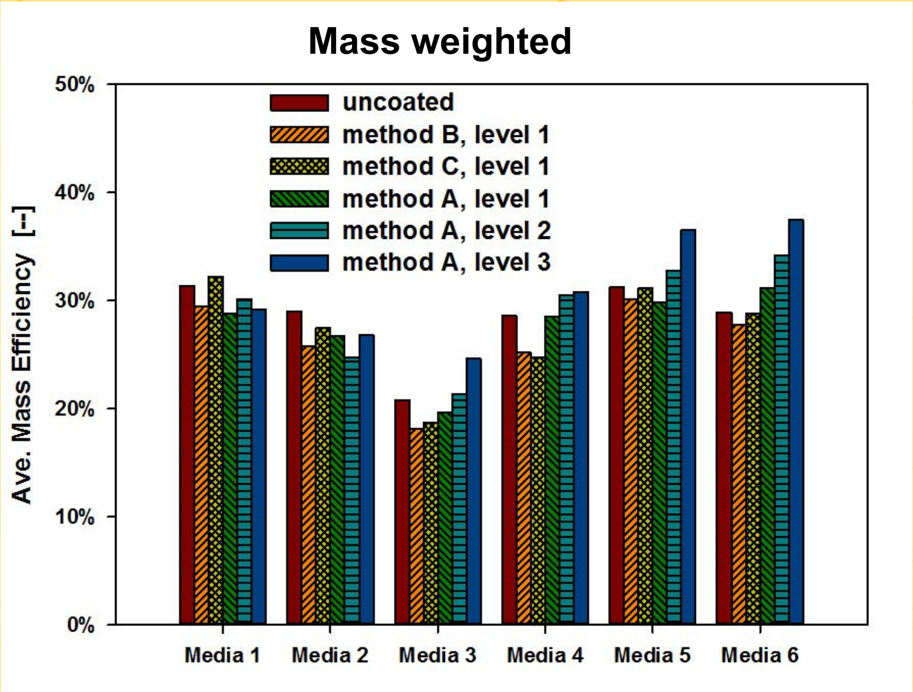
Soot removal – Distribution weighted efficiency

- Number and mass weighted efficiencies are determined by assuming a GDI soot distribution at CMD=80 nm and σ_g=1.7, with a mass-mobility exponent of 2.3.

$$\overline{Eff_N} = \frac{\int Eff(D_p) N_p(D_p) d\log(D_p)}{\int N_p(D_p) d\log(D_p)}$$

$$\overline{Eff_M} = \frac{\int Eff(D_p)\rho_{eff}(D_p)\frac{\pi}{6}(D_p)^3 N_p(D_p) d\log(D_p)}{\int \rho_{eff}(D_p)\frac{\pi}{6}(D_p)^3 N_p(D_p) d\log(D_p)}$$

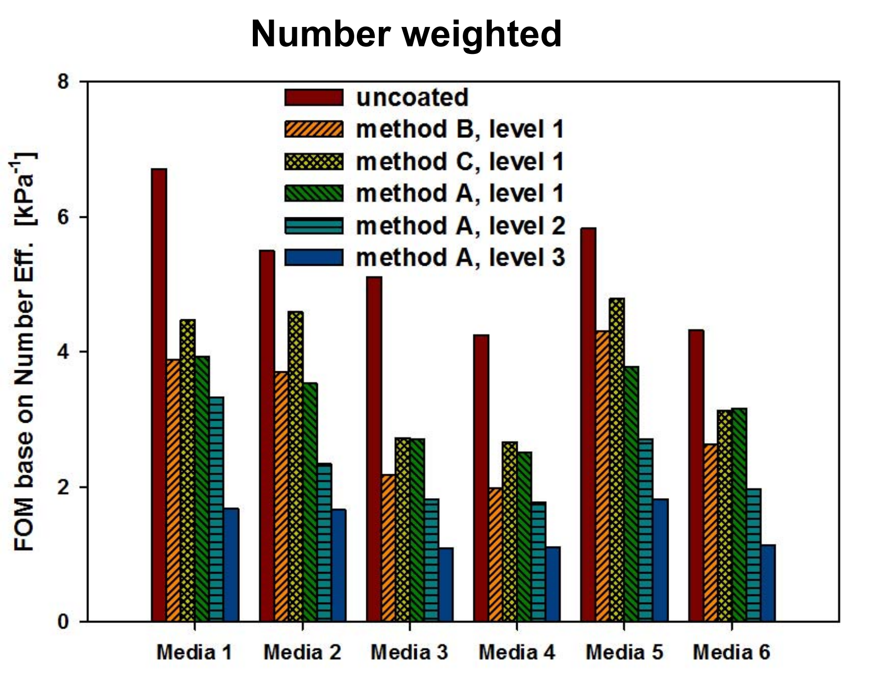


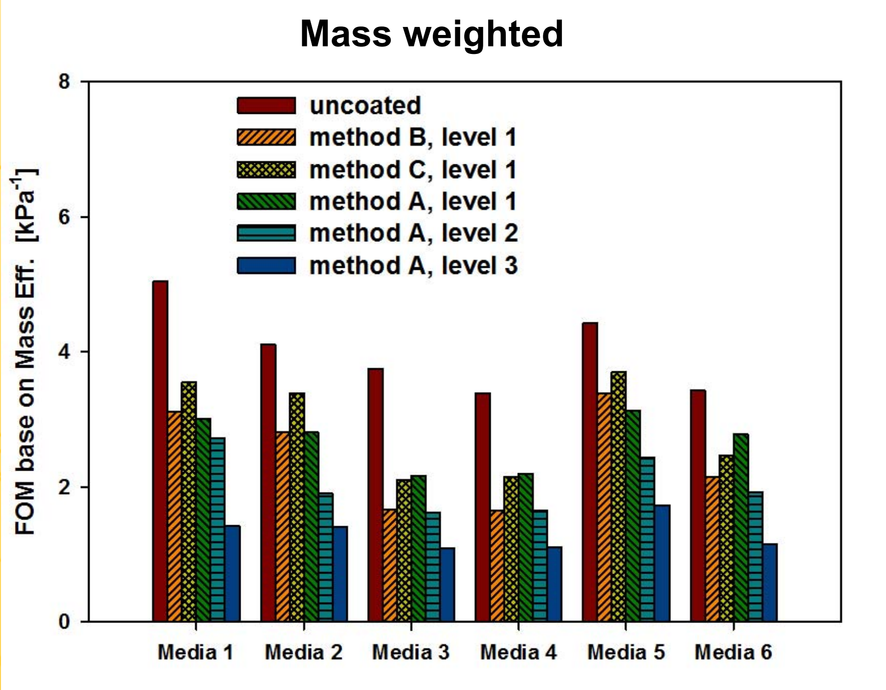


Soot removal – Figure of Merit (FOM)

- Flow resistance – filtration efficiency tradeoff is quantified using media Figure of Merit, with higher value preferred.

$$FOM_N = -\ln\left(1-\overline{Eff_N}\right)/\Delta P \qquad FOM_M = -\ln\left(1-\overline{Eff_M}\right)/\Delta P$$

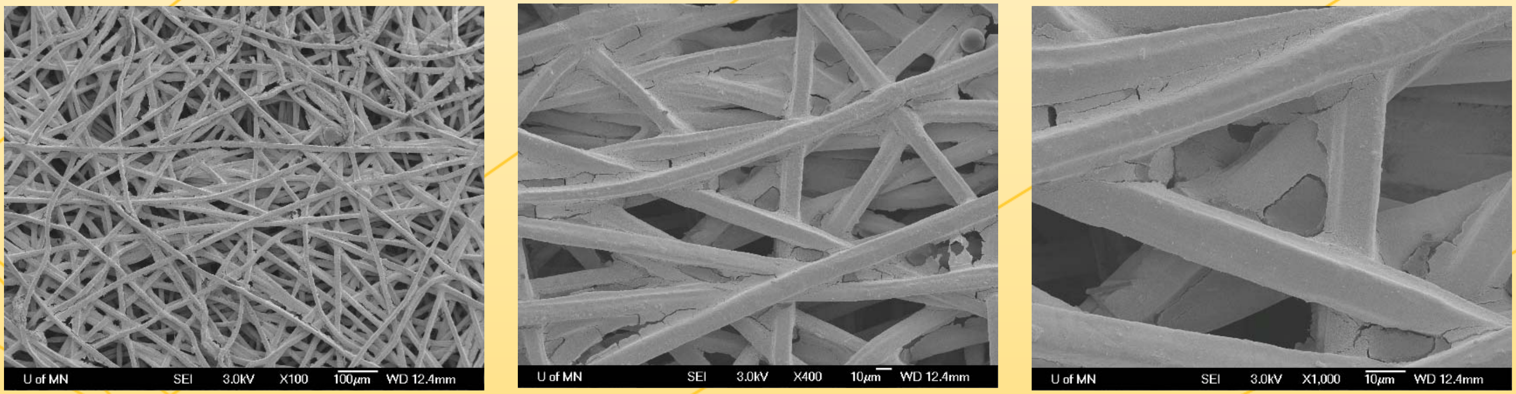




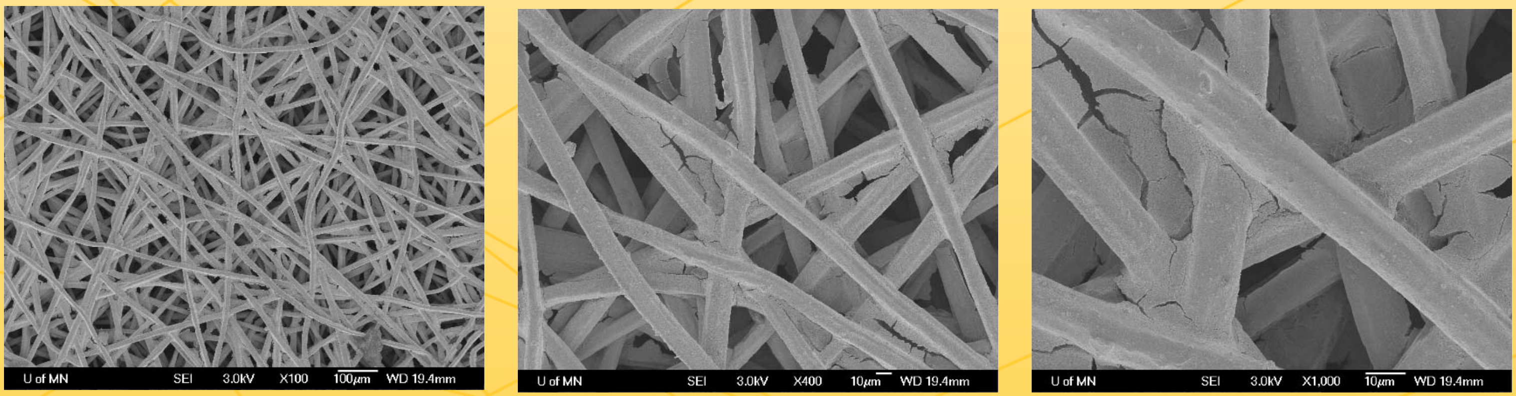
- FOMs decrease with coating level (amount) for all media grade.
- At coating level 1, coating method C seems to have slightly (less than 30%) higher FOMs than method A & B.

SEMs of the coated samples

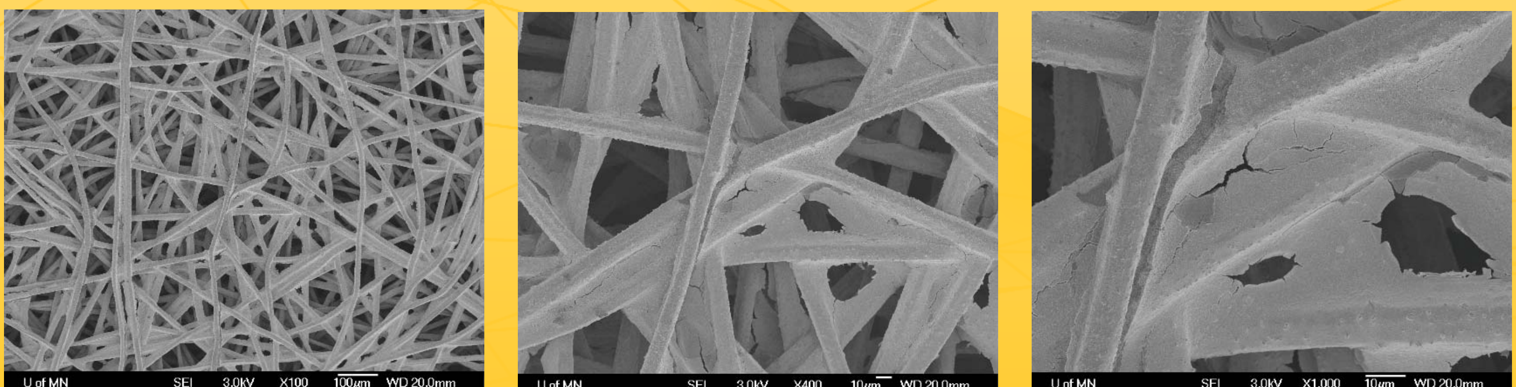
2-1-1A



2-1-1B

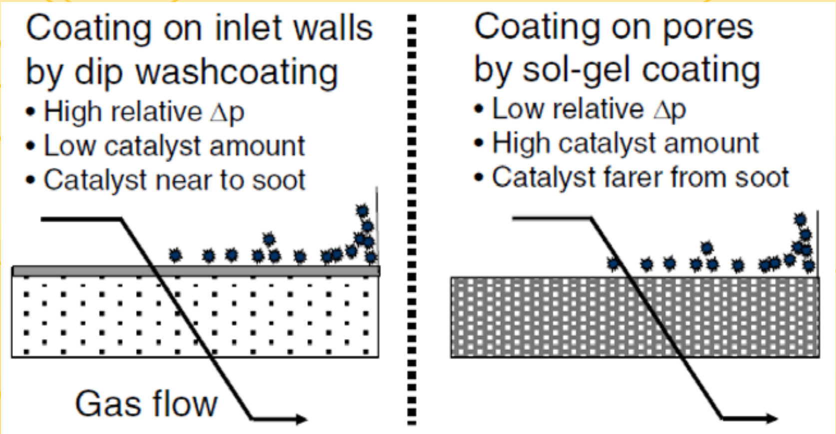


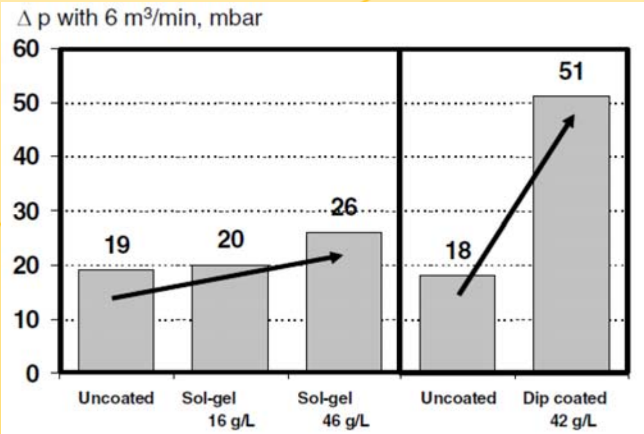
2-1-1C



Discussions

- For conventional ceramic wall substrate, two major coating patterns exist: **on-the-wall** and **in-the-wall**.





(SAE 2007-01-0041)

- Coating pattern on metal fiber media is similar to the in-the-wall coating pattern on wall substrate, which tends to introduce less pressure penalty than the on-the-wall pattern. Coated media has reasonably low backpressure similar to wall-flow counterpart, although direct comparison data is not available.
  – Total ΔP increase on wall-flow substrate at moderate coating level in reference: 7-25%.
  – Estimated contribution of media ΔP on total ΔP: 10-20%.
  – Estimated media ΔP increase: **28-225%**.
  – Measured media ΔP increase for metal fiber media at coating level 1 in current study: **14-94%**.

Summary

- Three-way catalyst wash coating is successfully applied onto sintered metal fiber filter media for potential application on catalyzed GPFs.
- Filtration performance of the coated 1” disk samples were evaluated using soot particles generated from a home-made diffusion flame burner.
- Backpressure of coated samples increases with increasing wash-coating levels. At coating level 1 (more realistic by estimation), the backpressure increases by 14 to 94% from the uncoated samples.
- Filtration efficiency of coated samples slightly decreases at small sizes (diffusion-dominated) while slightly increases at larger sizes (interception-dominated). The change of distribution integrated efficiency is within 6% for all cases.
- SEMs indicate wash coating stays inside media, coating on metal fiber surface, but with bridging especially at fiber intersections.
- TWC conversion efficiency will be evaluated to better compare to coated media performance to its wall-flow substrate counterpart.

Appendix

Sample #	Wash-coating loading		Solidity change*
	g/in³	wt.%	[%]
1-1-1A	1.29	4.45	2.6
1-1-2A	1.29	4.50	2.6
1-2-1A	2.02	7.17	4.1
1-2-2A	2.14	7.02	4.4
1-3-1A	3.60	11.98	7.3
1-3-2A	3.72	13.41	7.6
1-1-1B	1.29	4.47	2.6
1-1-2B	1.29	4.61	2.6
1-1-1C	1.21	3.79	2.5
1-1-2C	1.21	4.22	2.5

Sample #	Wash-coating loading		Solidity change*
	g/in³	wt.%	[%]
2-1-1A	1.46	4.19	3.0
2-1-2A	1.35	4.22	2.7
2-2-1A	2.21	6.47	4.5
2-2-2A	2.21	6.89	4.5
2-3-1A	3.88	10.96	7.9
2-3-2A	3.88	11.69	7.9
2-1-1B	1.40	4.45	2.8
2-1-2B	1.51	4.31	3.1
2-1-1C	1.46	4.25	3.0
2-1-2C	1.08	4.49	2.2

Sample #	Wash-coating loading		Solidity change*
	g/in³	wt.%	[%]
3-1-1A	1.29	3.18	2.6
3-1-2A	1.13	3.17	2.3
3-2-1A	1.70	4.75	3.5
3-2-2A	2.10	5.34	4.3
3-3-1A	3.56	8.91	7.2
3-3-2A	4.04	11.01	8.2
3-1-1B	1.13	3.00	2.3
3-1-2B	1.29	3.24	2.6
3-1-1C	1.21	3.44	2.5
3-1-2C	1.05	2.56	2.1

Sample #	Wash-coating loading		Solidity change*
	g/in³	wt.%	[%]
4-1-1A	1.62	2.94	3.3
4-1-2A	1.51	2.75	3.1
4-2-1A	2.26	4.05	4.6
4-2-2A	2.37	4.22	4.8
4-3-1A	3.34	6.86	6.8
4-3-2A	4.64	8.43	9.4
4-1-1B	1.19	2.32	2.4
4-1-2B	1.29	2.39	2.6
4-1-1C	1.40	2.58	2.8
4-1-2C	1.19	2.25	2.4

Sample #	Wash-coating loading		Solidity change*
	g/in³	wt.%	[%]
5-1-1A	1.62	5.95	3.3
5-1-2A	1.37	4.91	2.8
5-2-1A	2.02	7.08	4.1
5-2-2A	1.94	7.45	3.9
5-3-1A	3.72	13.14	7.6
5-3-2A	3.80	13.95	7.7
5-1-1B	1.21	4.87	2.5
5-1-2B	1.29	4.98	2.6
5-1-1C	1.21	4.31	2.5
5-1-1C	1.13	4.32	2.3

Sample #	Wash-coating loading		Solidity change*
	g/in³	wt.%	[%]
6-1-1	1.94	4.11	3.9
6-1-2	1.78	3.93	3.6
6-2-1	2.10	4.83	4.3
6-2-2	2.10	4.61	4.3
6-3-1	3.56	7.97	7.2
6-3-2	4.37	9.78	8.9
6-1-1B	1.46	3.19	3.0
6-1-2B	1.94	4.30	3.9
6-1-1C	1.29	3.01	2.6
6-1-1C	1.13	2.38	2.3

*: assuming wash-coating density of 3 g/cc

Backup: Flow resistance