12th VERT Forum, March 24th 2022

VERT PROJECT

PARTICLE FILTER CONCEPT
for
HFO ENGINES

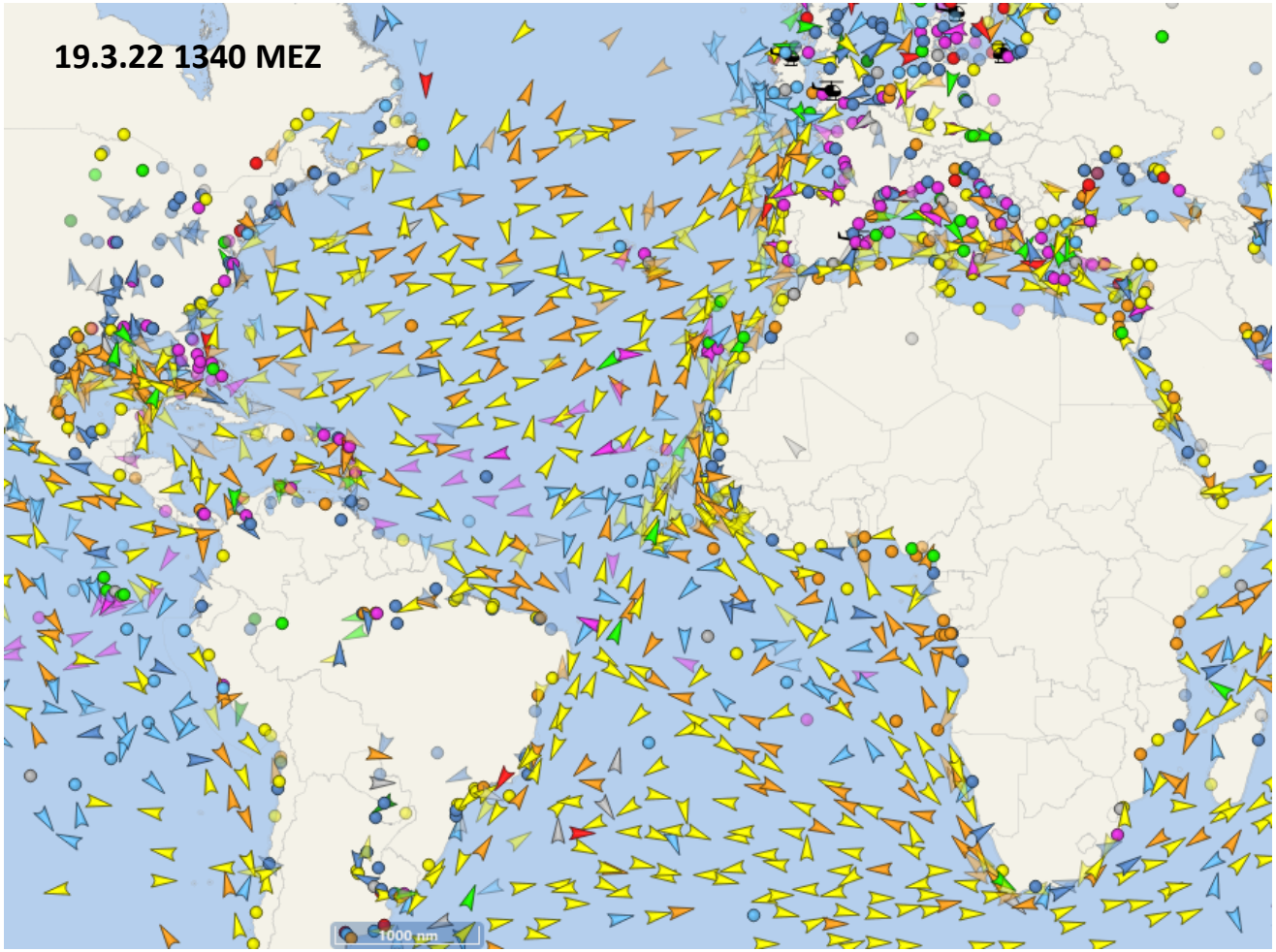
2019 - 2021

Thomas Lutz / Andreas Mayer

BACKGROUND and TARGET

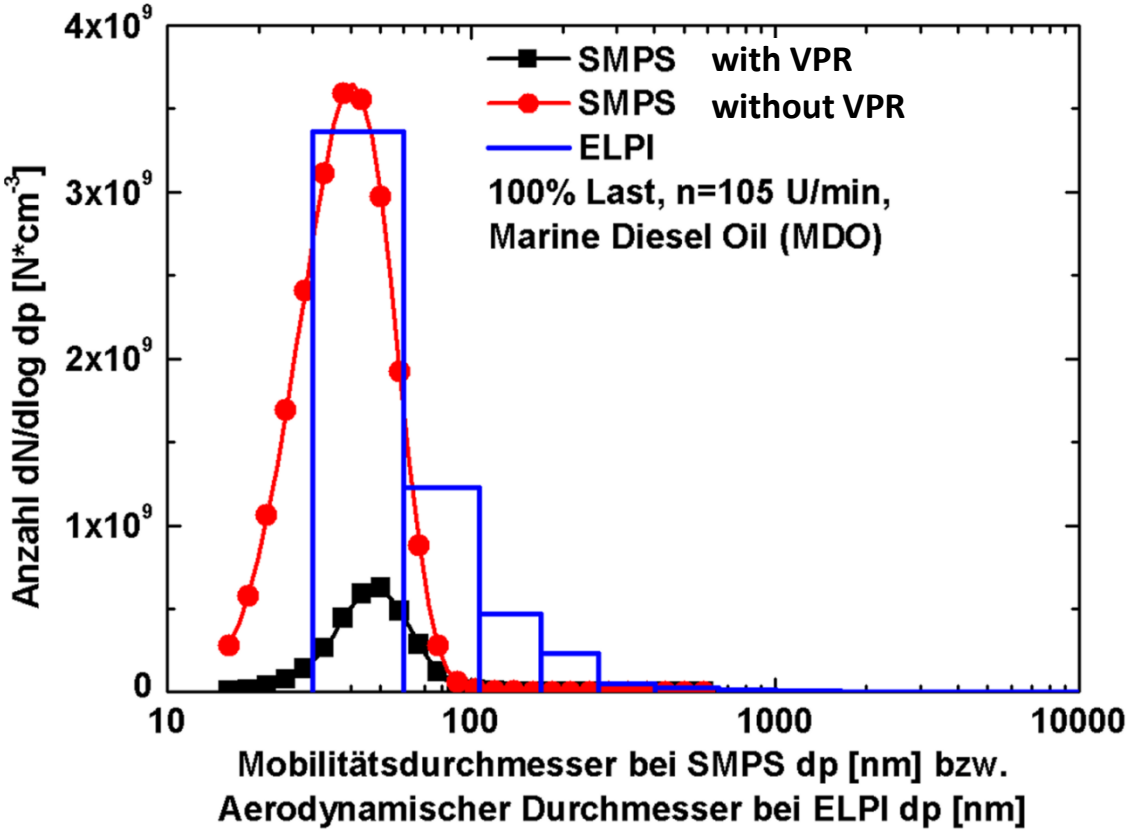
- Marine contribution to global PM-burden
  (BC impact on the actic/global warming)
- Marine diesel fuel properties → ***sulfur*** and ***ash***
- PM characteristics *(e.g. high OC and SOF content)*
- Standard wall flow DPF not feasable
- Filter cleaning and de-ashing in situ
- → **A membrane filter based concept**

SHIP TRAFFIC ON THE ATLANTIC OCEAN



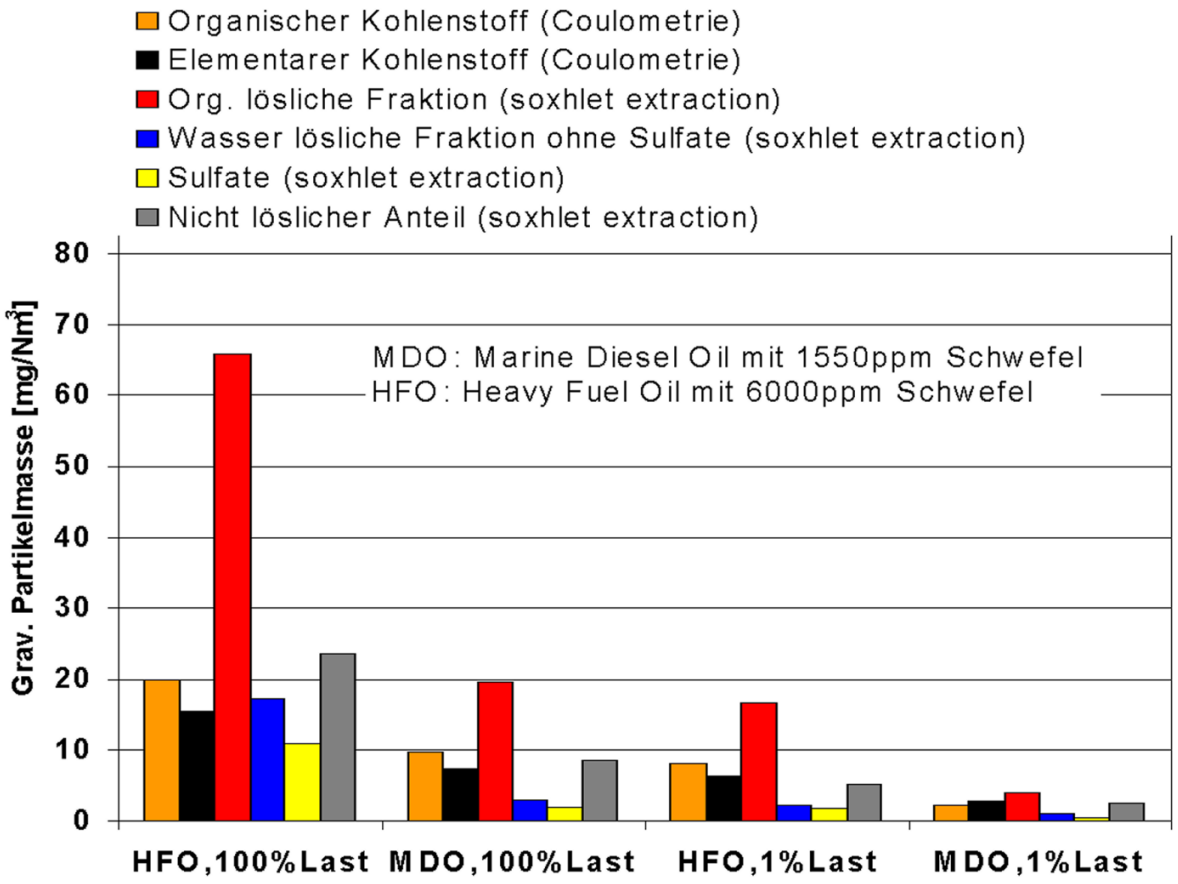
TYPICAL PARTICLE SIZE DISTRIBUTION

SULZER 4 RT-flex 58T-B (2-stroke engine) – MDO



Source: KTI Project 4207.2 KTS

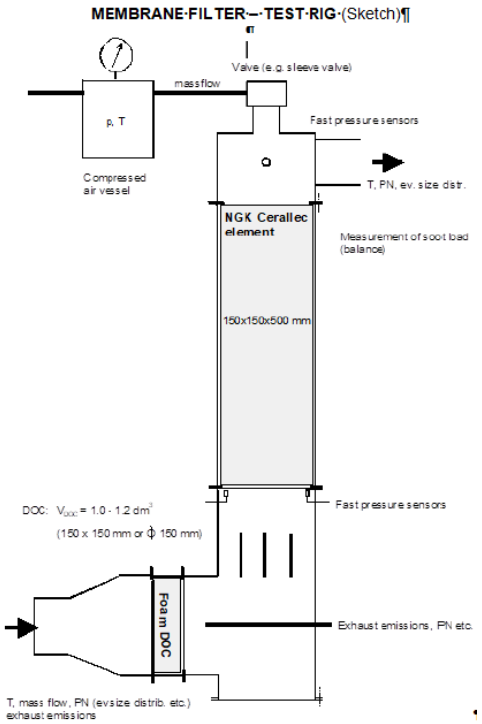
PARTICLE COMPOSITION



Source: KTI Project 4207.2 KTS

CONCEPT

To cover the problems due to ash, sulfur, high OC, low T, low backpressure



- Surface Filtration by ceramic membrane wall flow filter (for ash cleaning)
- Particle «drying» by OC catalysis on foam catalyst - electrically heated if needed (SiC)
- Periodical cleaning by compressed air from clean side
- During engine operation eventually with bypass
- Modular design to cover high exhaust volume flow
- DeNOx downstream not part of the project
- De-Sulfurization not part of the project

WHAT WAS THE TARGET?

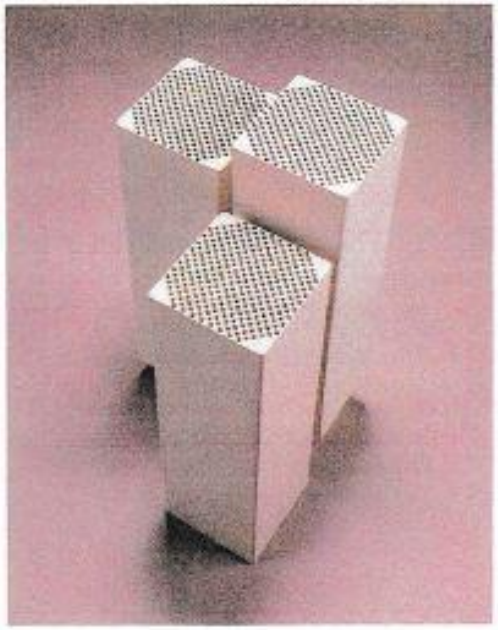
To test the concept as realistic as possible on small scale but on real engines (4S & 2S) for different fuels to reach 99 % PN removal

- Diesel fuel with 1000 ppm Sulfur and 1:16 lubrication oil *(in Biel)*
- Heavy fuel oil HFO (high S and ash) at *WinG&D* (2S bypass);
- Alternative: FVTR Rostock (4S)

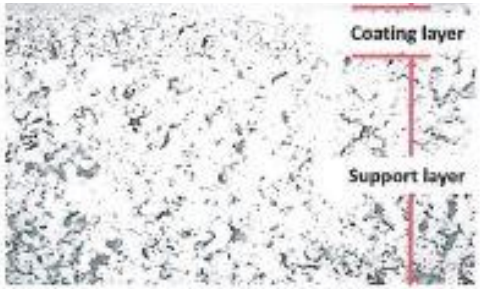
Source: BFH Biel/CH

NGK MEMBRANE FILTER

Characteristics of ceramic filter



Material	Cordierite
Working temperature	Up to 900 ℃
Dimensions	150□ × 500L
Cell pitch / Filtration area	4mm / 4.0m² 6mm / 2.6m²
Pore size (support layer) (coating layer)	Approx. 15μm Approx. 5μm
Porosity	45%
Coefficient of thermal expansion	1 × 10⁻⁶/℃

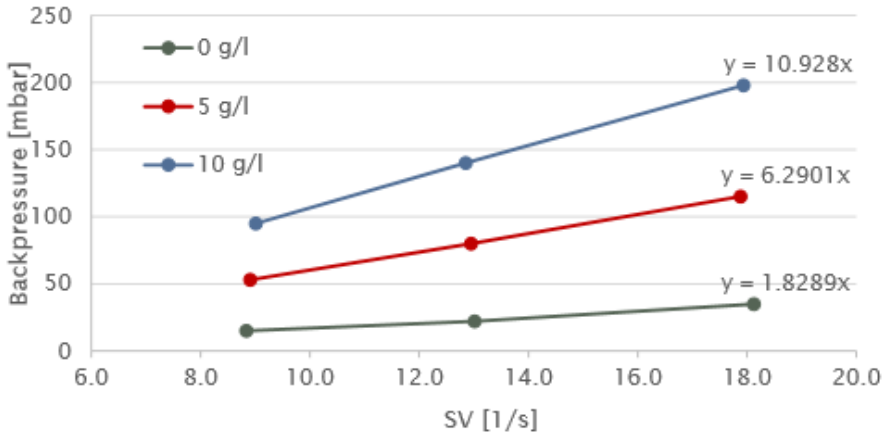


Cross section of filter

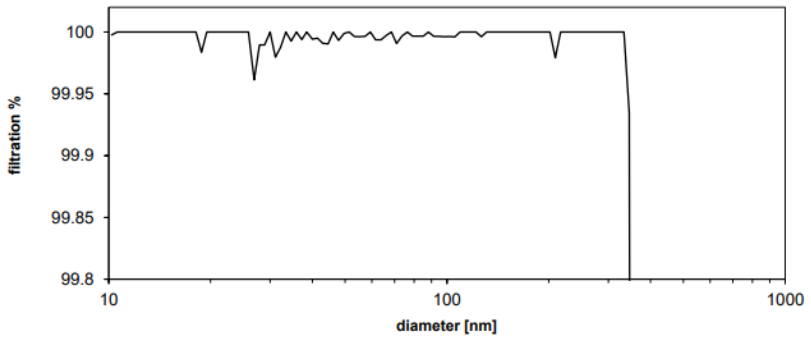
Source: NGK 2016

FILTER CHARACTERISTICS

- Backpressure behavior after (partial) regeneration



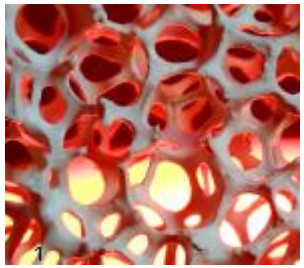
Filtration efficiency
(of new and unloaded filter)

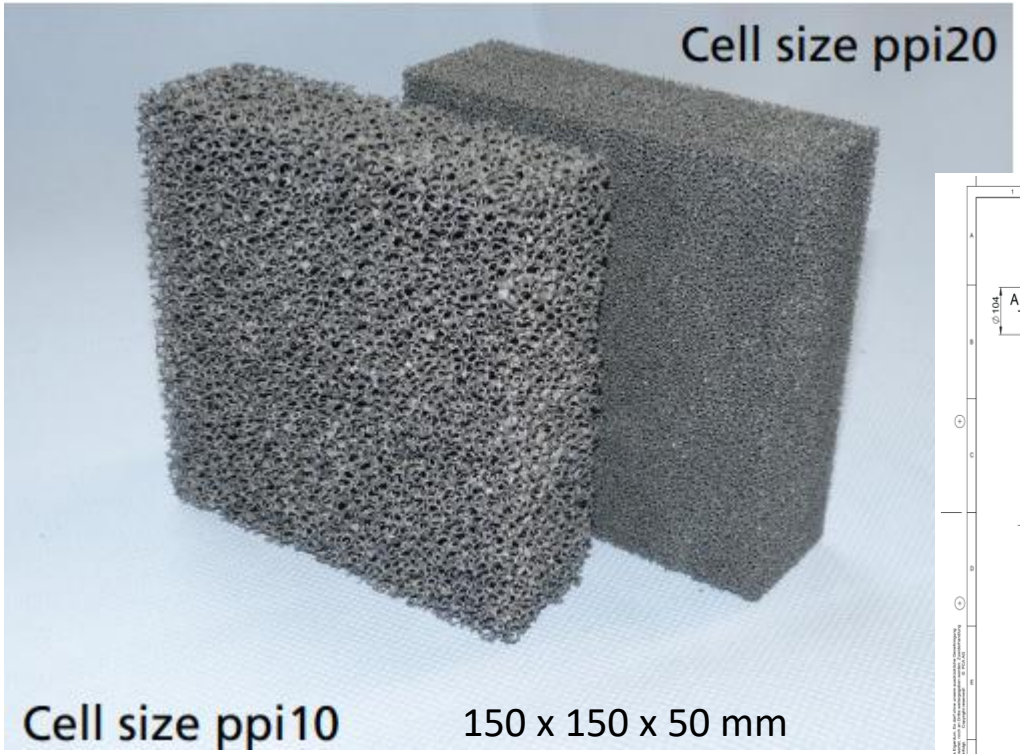


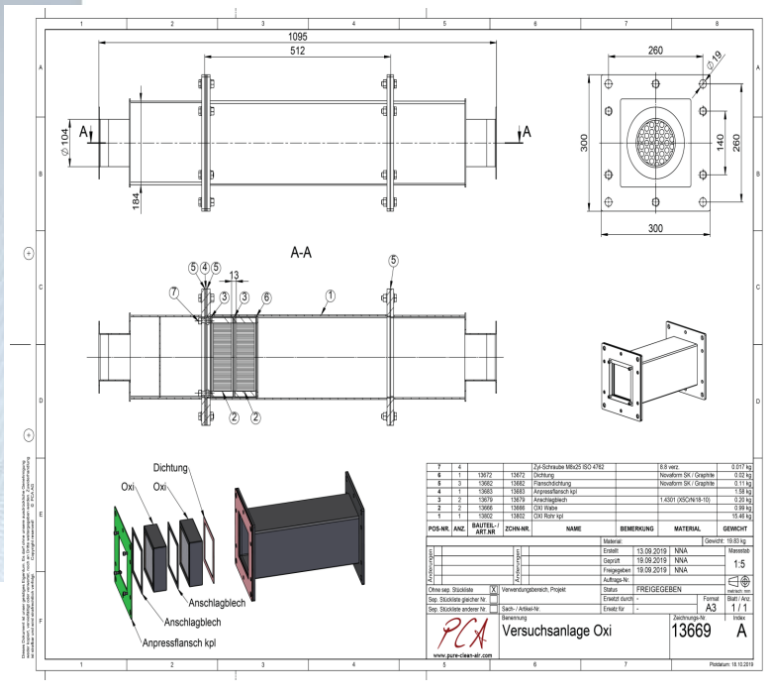
Source: Report 532a, BFH Biel/CH

OPEN FOAM DOC

Fraunhofer-Institut Dresden (foam)/Umicore (catalyst)

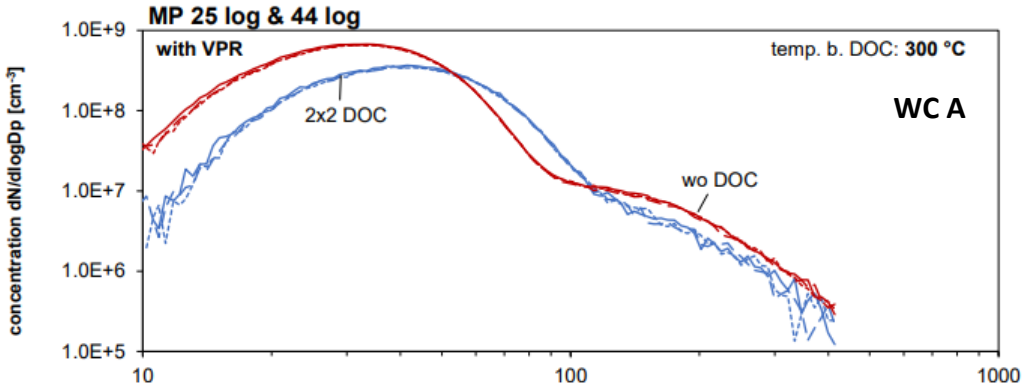






Source: Fraunhofer IKTS, Dresden

DOC EFFECTS (washcoats A and B)



FOAMS

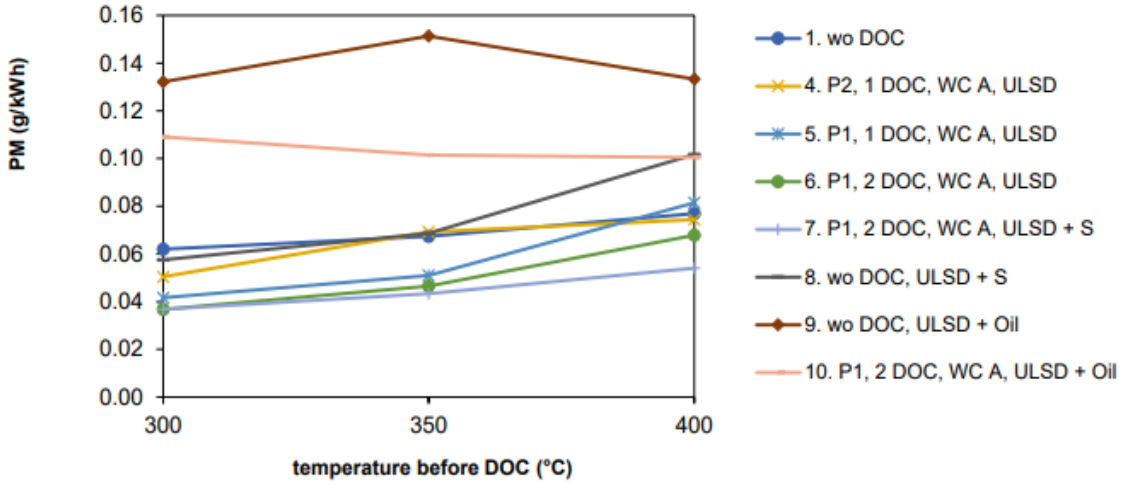
- 20 ppi (P1) better than 10 ppi (P2)
- Mass transfer dominated by diffusion
- Deposition OK for diesel fuel
- Plugging with HFO

Washcoat

- WC A reaches 50-60% conversion of OC; no sensitivity to S
- WC B shows very little conversion

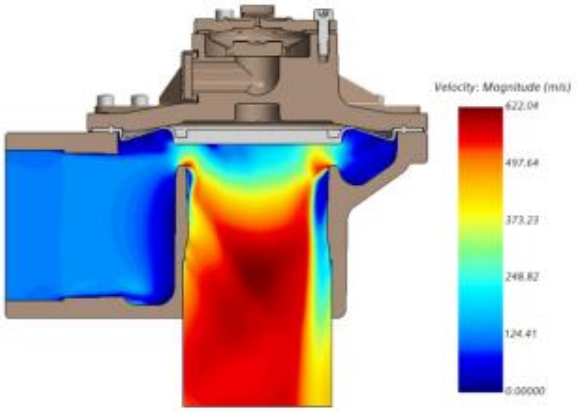
Spacial velocity

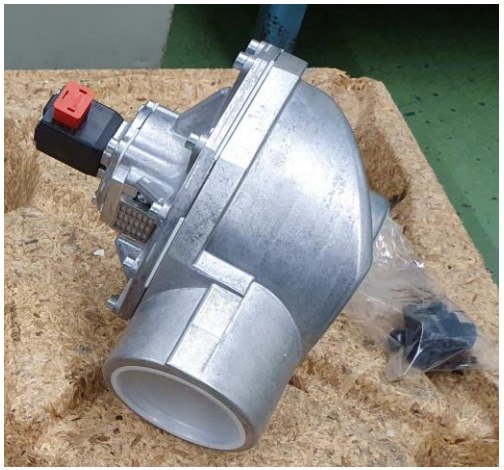
- 2x2 units is not the optimum



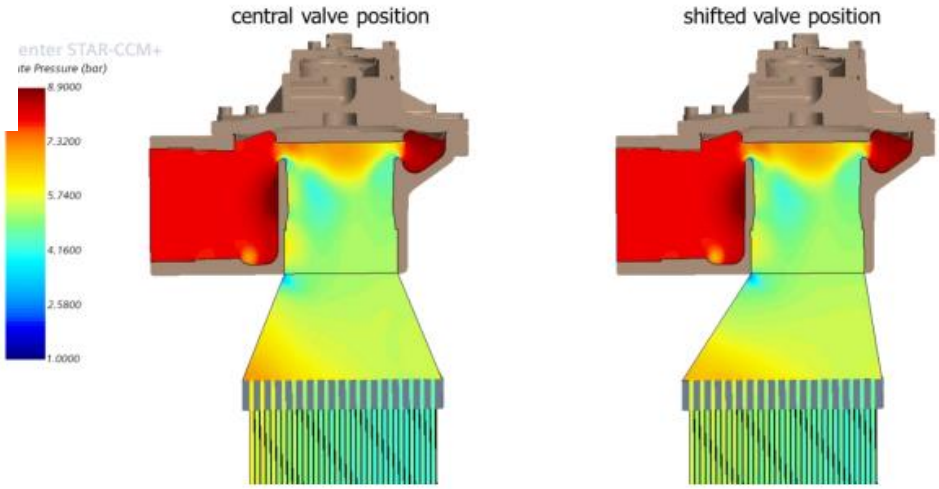
Source: Report B532b, BFH, Biel/CH

BLOW OUT TESTS – FLOW SIMULATION



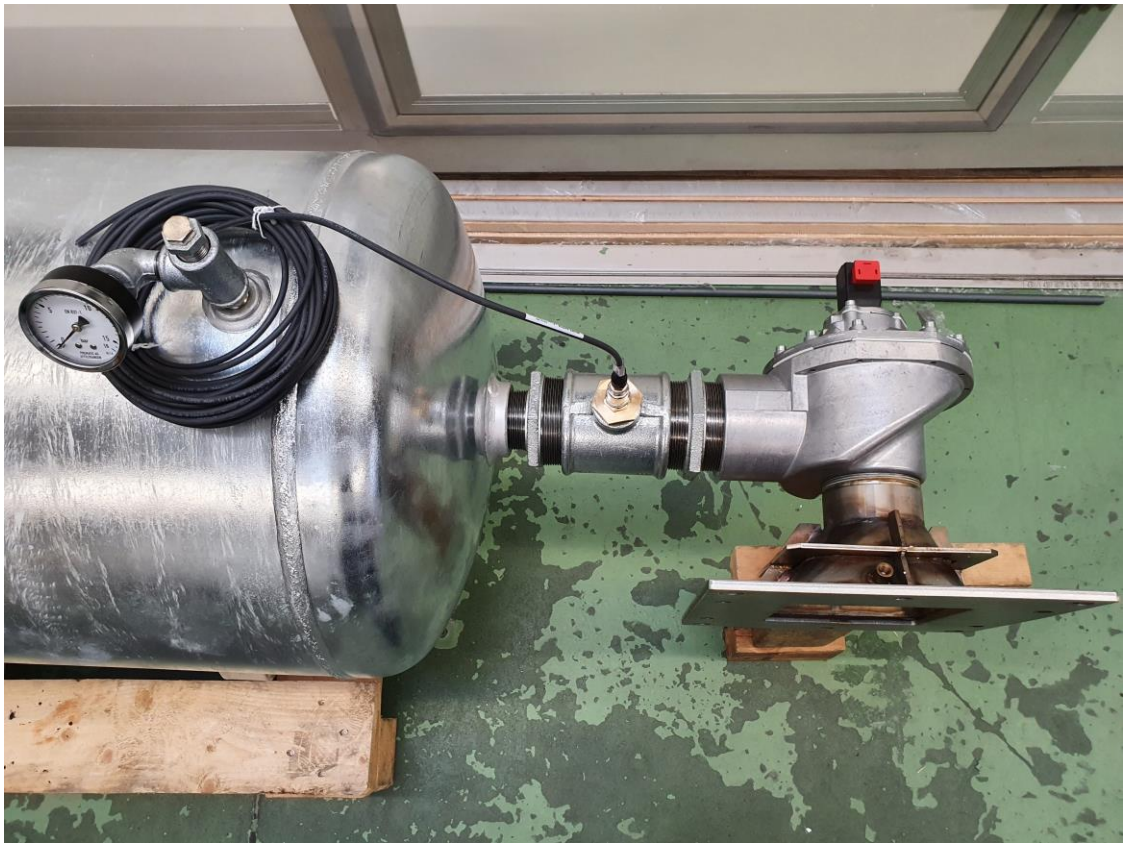


Optimization of the transition piece from the inlet valve to the filter housing



Source: CFS GmbH, Zürich

BLOW OUT TESTS – TEST FACILITY



Norgren soot blower valve

Transition piece to the filter housing

Source: BFH Biel/CH

BLOW OUT TESTS – FILTER LOADING (HFO)

FILTER

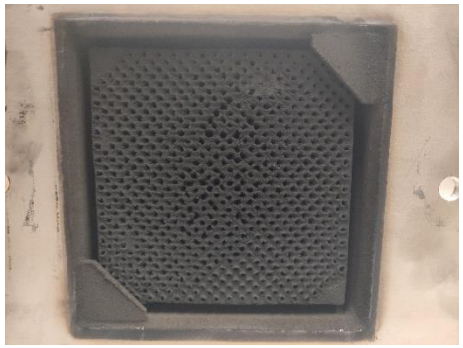
PARTICLE SIZE DISTRIBUTION

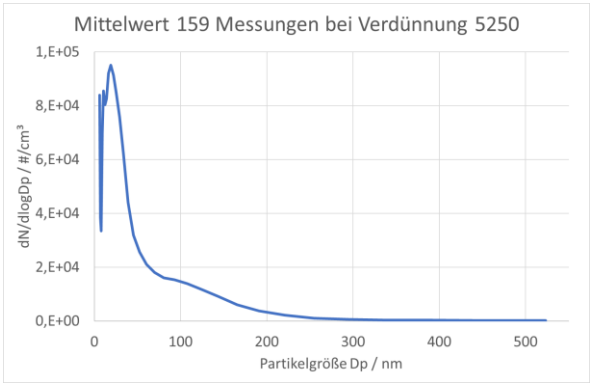
DOC

after loading

outlet

inlet





SOURCE: Proj.Nr.21/06/05 – FVTR Rostock

BLOW OUT TESTS – CLEANING PROCESS

Test-Video (4 bar / 120 ms Valve Actuation Time)

BLOW OUT TESTS – FIRST RESULTS

Filter #	Catalytic Coating	Empty Filter Weight	Soot Type (Used Fuel)	ATS	Temp. bef. ATS During Loading	Soot Loaded Filter Weight	Soot Load	Blowing Pressure	1st Blow	Δ	η_1	2nd Blow	Δ	η_2	3rd Blow	Δ	η_3	η_{tot}	Test Valid
		g			deg. C.	g	g/l	bar	g	g		g	g		g	g			
3	no	21163.1	ULSD	-	≈ 250	21295.8	11.8	2	21197.1	98.7	**74.4%**	21193.4	3.7	**2.8%**	21191.8	1.6	1.2%	**78.3%**	yes
3	no	21163.7	ULSD+Oil	-	≈ 250	21291.9	11.4	2	21204.1	87.8	**68.5%**	-	-	-	-	-	-	**-**	yes
3	no	21162.8	ULSD	-	≈ 250	21292.2	11.5	4	-	-	**-**	-	-	-	21195.2	97	75.0%	**75.0%**	yes
6	yes	22127.0	ULSD	-	≈ 250	22227.1	8.9	4	-	-	**-**	-	-	-	-	-	-	**-**	no
5	yes	22563.1	ULSD	-	≈ 250	22661.0	8.7	4	-	-	**-**	-			22547.7	113.3	115.8%	**115.8%**	yes
4	no	21208.4	HFO	-	300	21531.3	28.7	4	21392.4	138.9	**43.0%**	-	-	-	21384.4	146.9	45.5%	**88.5%**	yes
1	no	20811.7	HFO	DOC	300	21048.8	21.1	4	-	-	**-**	-	-	-	20884.5	164.3	69.3%	**69.3%**	yes
2	no	20793.4	HFO	DOC	400	20871.4	6.9	4	-	-	**-**	-	-	-	20797.4	74	94.9%	**94.9%**	yes

Filter Volume	11.25	l
Valve Actuation Time	120	ms

Abbreviations

ATS	After Treatment System
DOC	Diesel Oxidation Catalyst
HFO	Heavy Fuel Oil
ULSD	Ultra Low Sulfur Diesel

Source: BFH Biel/CH

NOT EXECUTED TASKS

- No multifilter-model was build and tested - so we have no experimental input on upscaling
- Test at 2-stroke marine engine at WinG&D could not be performed because of organizational problems
- Test with HFO on a 4-stroke engine can not fully replace the 2-stroke operation
- Regeneration under engine running conditions was not performed either
- Number of loading/cleaning repetitions is to small

PROVE OF THE CONCEPT

- The overall concept has been proven to be viable and feasable in principle
- The ceramic membrane wall flow filter is the most suitable solution for this application to work at low temperature with low backpressure
- OC elimination by catalysis to counteract filter plugging works but needs improvement
- Pulse cleaning works well but might need a more sophisticated valve and flow distribution design
- System proved insensitive to increased sulfur and oil ash

PARTNERS

- **Main financial Support**

  FEDERAL OFFICE FOR THE ENVIRONMENT (FOEN)

- **Research Partners**

  - BFH *(testing)*
  - Combustion and flow solutions GmbH
    (simulation of the pulse cleaning concept)

- **Industrial Partners**

  - NGK *(filter)*
  - LIEBHERR
  - WIN G&D
  - Pure Clean Air *(canning)*
  - UMICORE *(coating)*
  - Fraunhofer Institut
    (foam catalysts)

- **Project Management**: A. Mayer, Th. Lutz

Towards a blue sky and blue water

Thank you for your attention