A Counter Flow Denuder for Engine Exhaust Conditioning: First Laboratory Experiments

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DownToTen

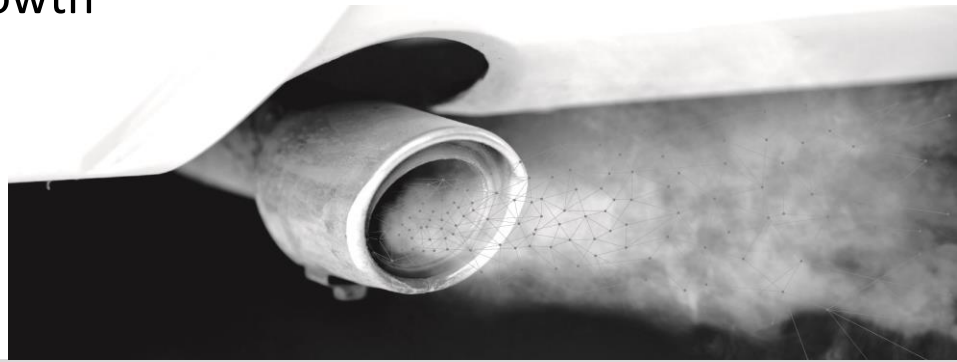
DownToTen is a Horizon 2020 funded project addressing engine exhaust particles down to at least ten nanometers

- → Description of the nature of sub 23 nm particles
- → Development of a robust sampling and measurement methodology
- → Set up a PN-PEMS demonstrator
- → Assessment of the fraction of particles left out of control (secondary aerosol)

Motivation

Future European Emission standards
Regulation of **SOLID** particle number emissions **≥ 10 nm**

→ Removal of volatile particles
→ Inhibiting of sub-cut size particle growth
→ Prevention of nucleation



State of the art

Evaporation Tube

Hot dilution to lower partial pressure of volatile compounds in gas phase and providing residence time to evaporate volatile particles

Thermodenuder

Heating aerosol and adsorption of evaporated material using a cooled activated carbon adsorption section. Limited storage capacity.

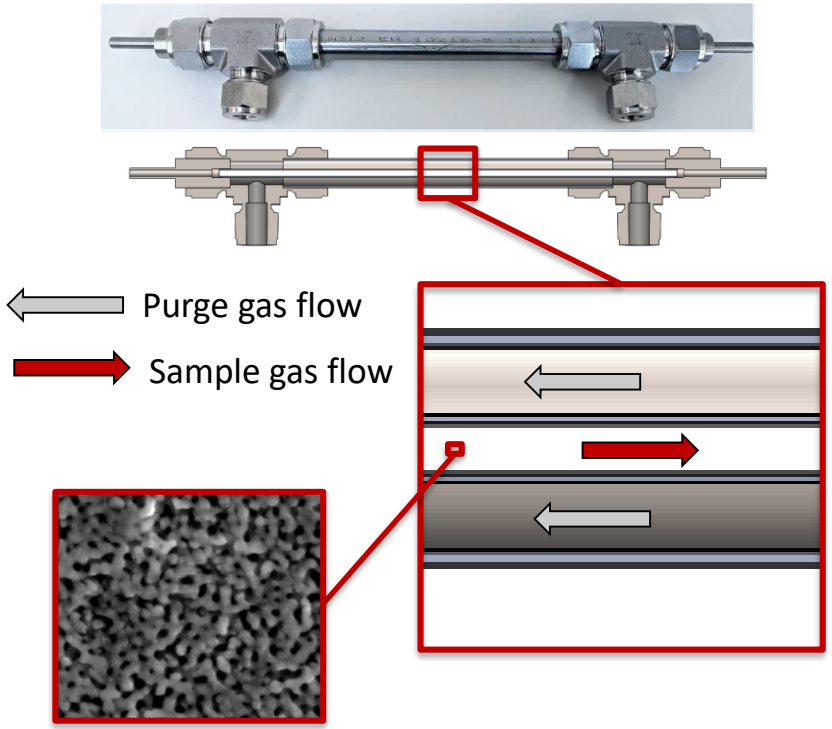
Catalytic Stripper

Oxidation of organic substances and storage of sulphur. Robust but high losses.

Counter Flow Denuder

Cylindrical porous glass membrane (sample flow)

Surrounded by concentric stainless steel tube (purge gas flow)



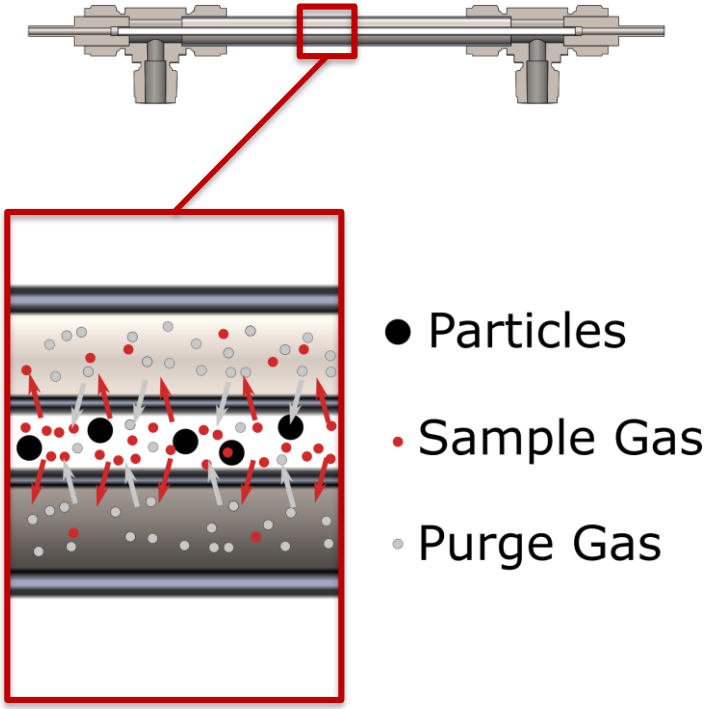
Hagino, H., 2017. Laboratory evaluation of nanoparticle penetration efficiency in a cylindrical counter flow denuder for non-specific removal of trace gases. *Aerosol Science and Technology*, *51*(4), pp.443-450.

Working Principle

Diffusional exchange of sample gases and purge gas

Driven by concentration gradient

Small effect on particles because of lower diffusivity than gas molecules



Advantages

Partial pressure of volatile compounds in gas phase is lowered by removing them

Transport in the purge gas flow eliminates the issue of limited storage capacities

No uncertainty-causing chemical reactions involved

Particle losses are very low

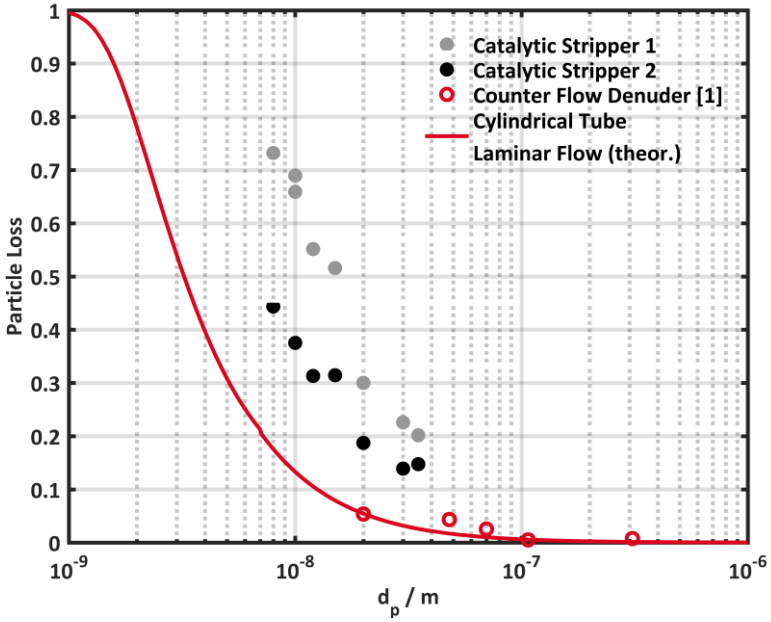
Particle Losses

Diffusional particle losses of the counter flow denuder match losses theoretical values for laminar flow through a cylindrical tube

→ Losses equal to evaporation tube

→ Active lowering of partial pressure

Losses of catalytic strippers are substantially higher



[1] Hagino, H., 2017. Laboratory evaluation of nanoparticle penetration efficiency in a cylindrical counter flow denuder for non-specific removal of trace gases. *Aerosol Science and Technology*, *51*(4), pp.443-450.

Experiment

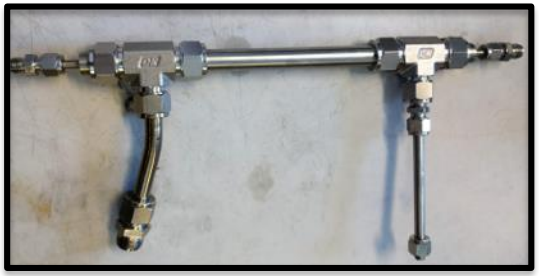
Generation of aerosol containing gaseous sulphuric acid and soot

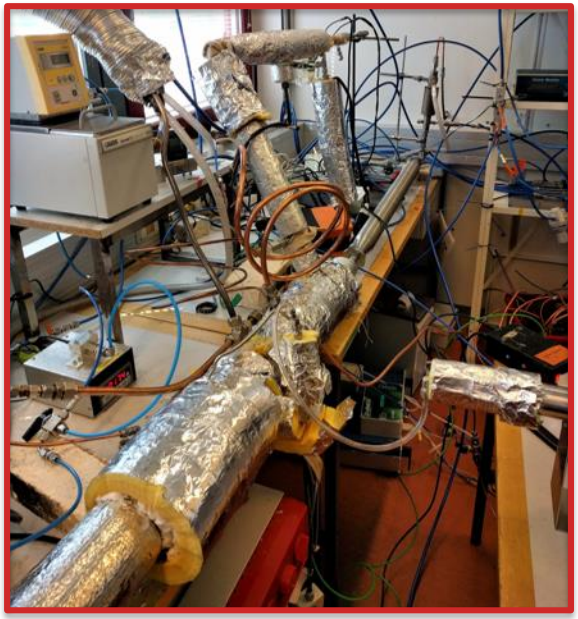
Cold dilution to induce the formation of a nucleation mode

Comparison of nucleation mode using counter flow denuder, evaporation tube or catalytic stripper for aerosol conditioning

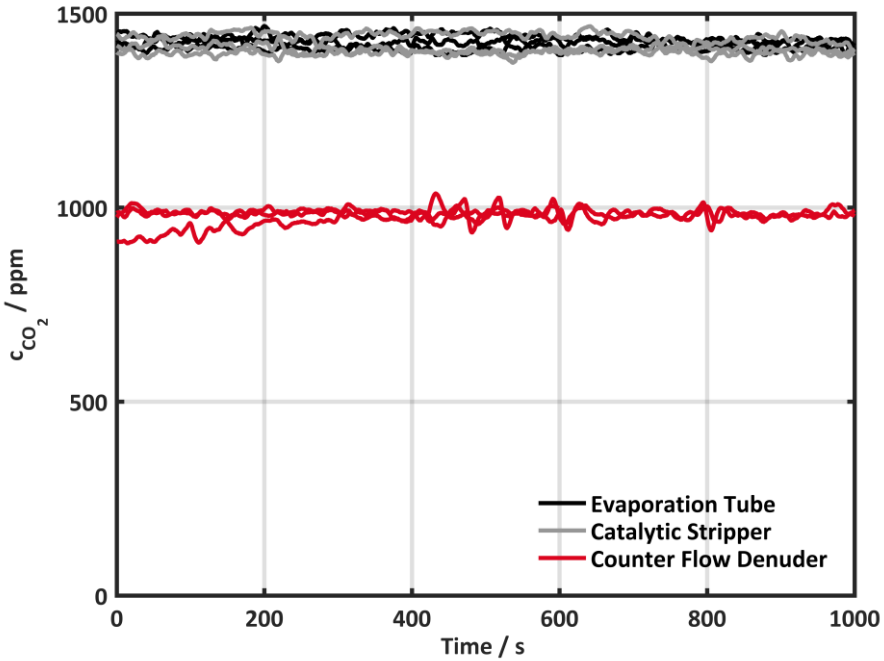
Experimental Setup

Experimental Setup

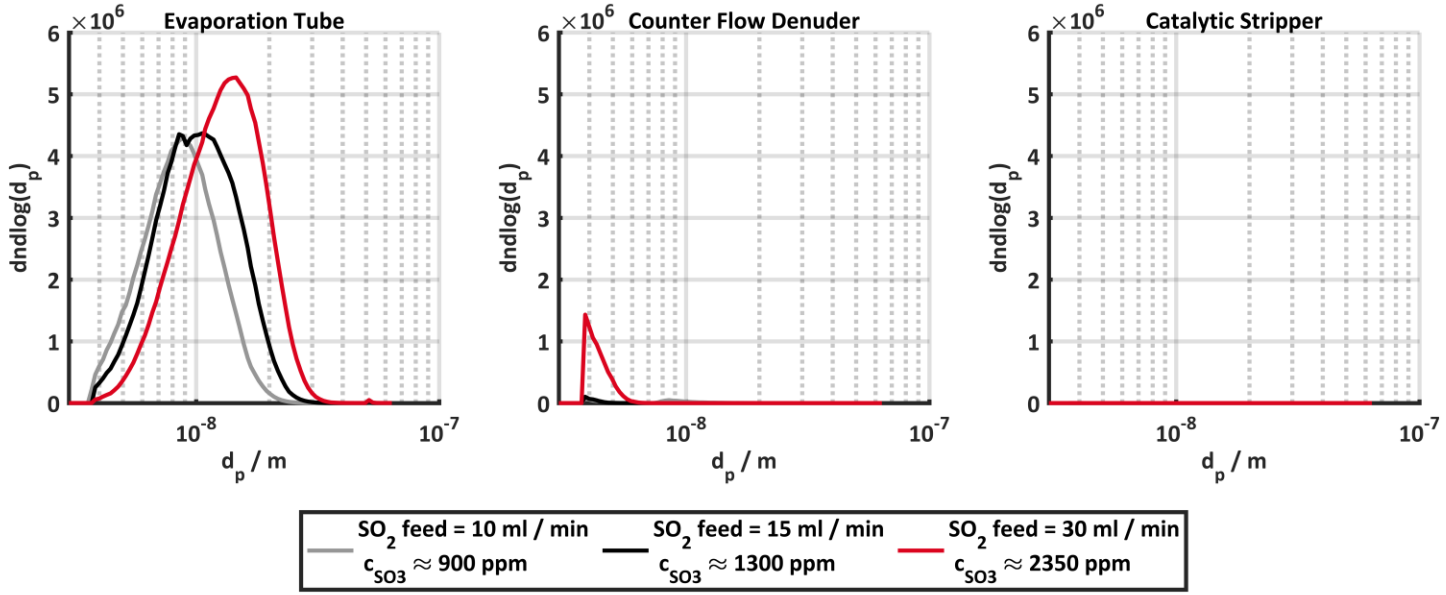




CO_2 Removal


1500
1000
500
0
c_{CO_2} / ppm
0
200
400
600
800
1000
Time / s
Evaporation Tube
Catalytic Stripper
Counter Flow Denuder

Nucleation Mode Prevention SMPS



Material Robustness

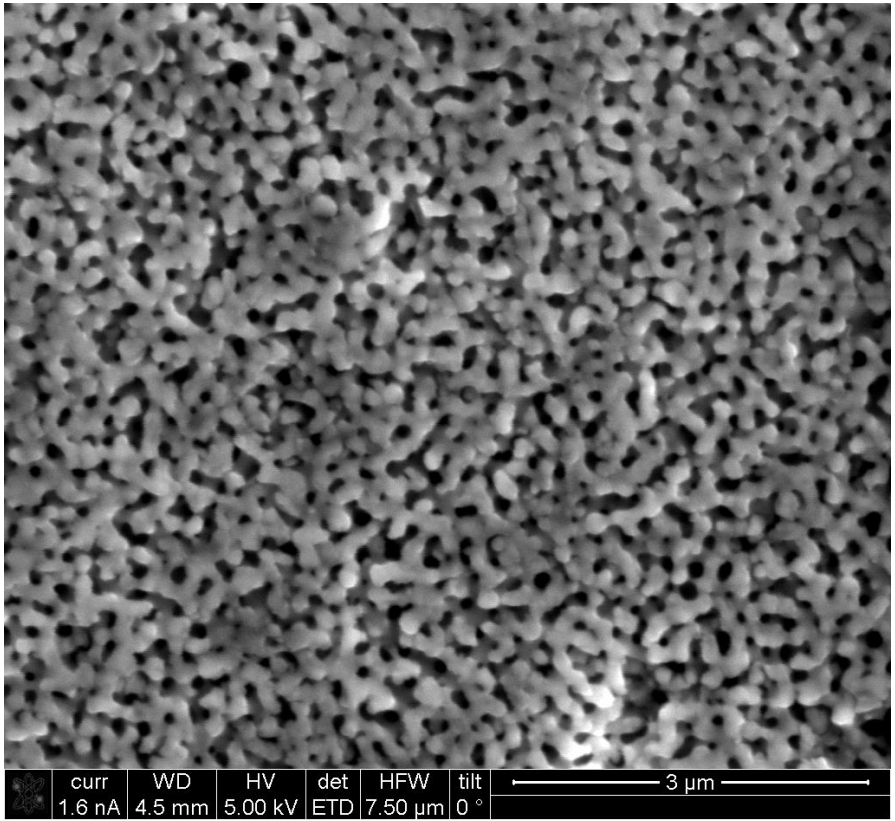
Gas exchange properties not compromised after contact with soot and sulphuric acid

Put 1 cm of porous material into 20 ml of H_2O for 15 minutes and measured pH value:

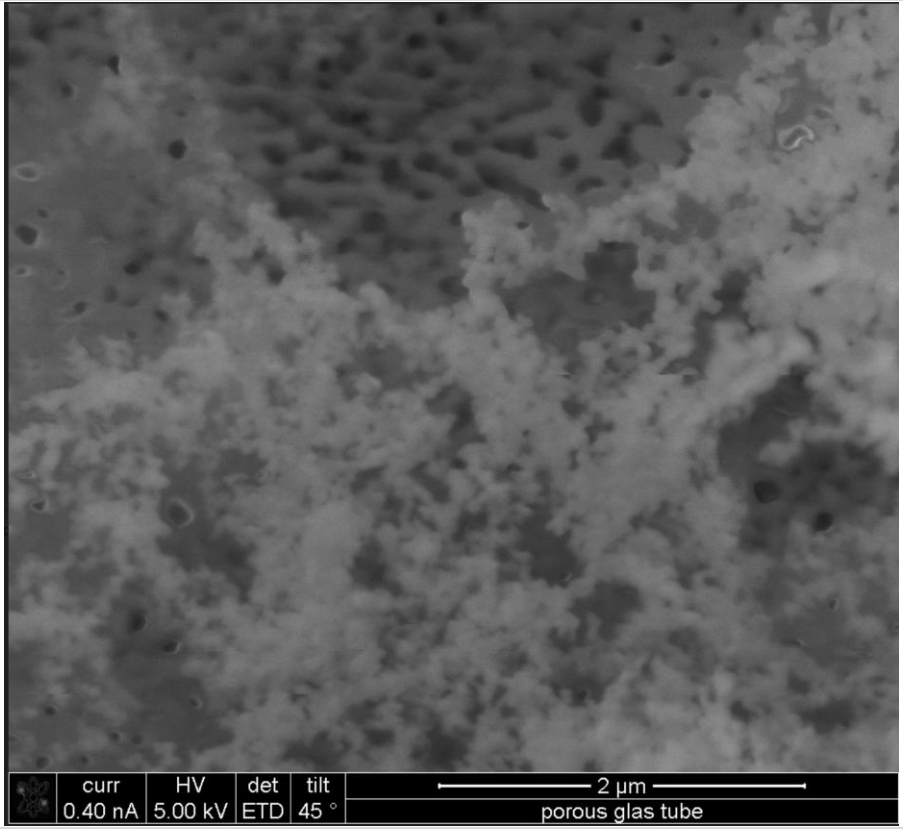
Before use: pH = 7.1
After use: pH = 7.1

→ No substantial storage of H_2SO_4 in membrane

Before



After



Conclusion

- Counter Flow Denuder causes low particle losses
- Showed that the counter flow denuder can be used hot (350°C)
- Effective nucleation mode prevention
- Removal of gaseous sulphuric acid
- Necessary to keep the pressure difference very low
- No substantial damage by heat, soot or sulphuric acid
- Gas exchange not compromised

WE ARE EXPLORING
THE **DOWN TO TEN**
WORLD OF EMISSIONS
AND WE WILL WORK
TOGETHER TO BRING IT
TO SUPER LOW LEVELS.