Water uptake by soot emitted during industrial fires: experimental results and application of a coupled multi-molecular adsorption/capillary condensation model.

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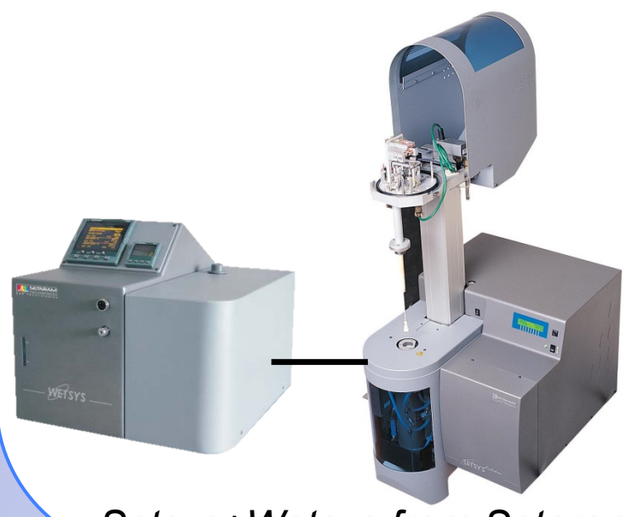
INTRODUCTION & GOALS

- Fire is the most probable hazardous risk in a nuclear facility, in such situation soot particles produced will directly impact the containment of this facility by increasing the pressure drop of High Efficiency Particulate Air (HEPA) filters. IRSN and LRGP have developed models for predicting the pressure drop of such filters by dry soot particles [1, 2]. Nevertheless, in case of fire, strong interactions between soot particles and gas/vapours are expected, which may significantly modify the aeraulic properties of the cake formed at the HEPA filter's surface.
- The aim of this first step is to investigate the sorption of water vapour (the most probable vapour produced during fires) at the surface of soot particles produced during realistic fire. Water sorption isotherms have been experimentally measured for particles produced by different fuels. In parallel, a multi-molecular adsorption/capillary condensation model [3] has been compared to these measurements.

Experimental Set-up

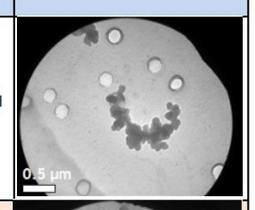
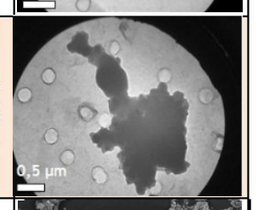
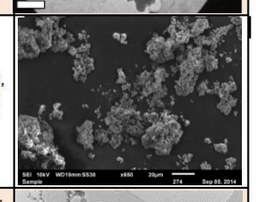
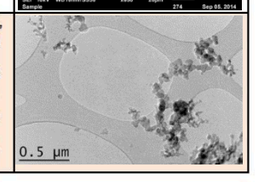
- Soot particles produced during small and large scales experiments.
- Morphology, composition, density and specific surface area investigated by transmission electron microscopy, pycnometry and BET.
- Water sorption isotherms measured with Setsys / Wetsys from Setaram and DVS Vacuum from Surface Measurement Systems.



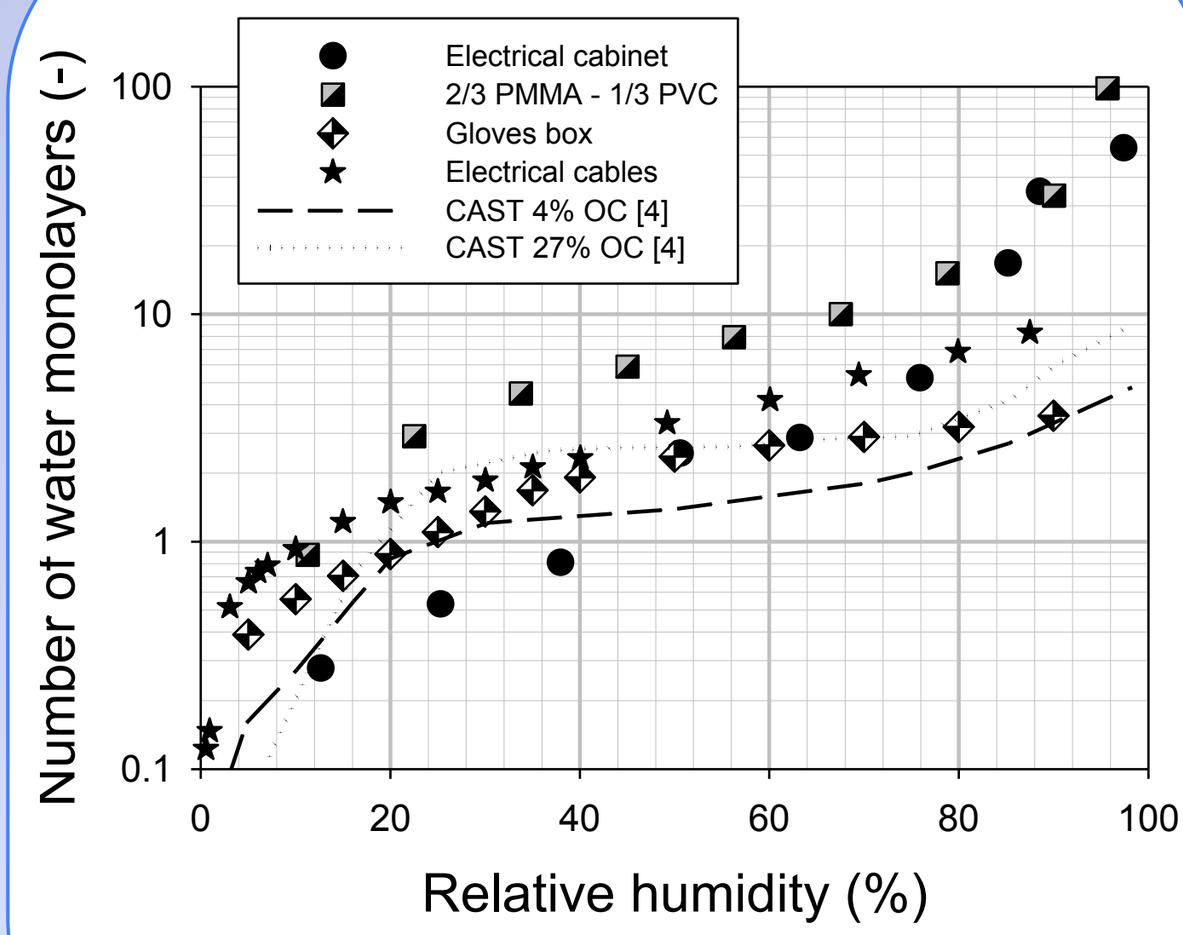
Setsys+Wetsys from Setaram

DVS Vacuum from SMS

Soot particles properties

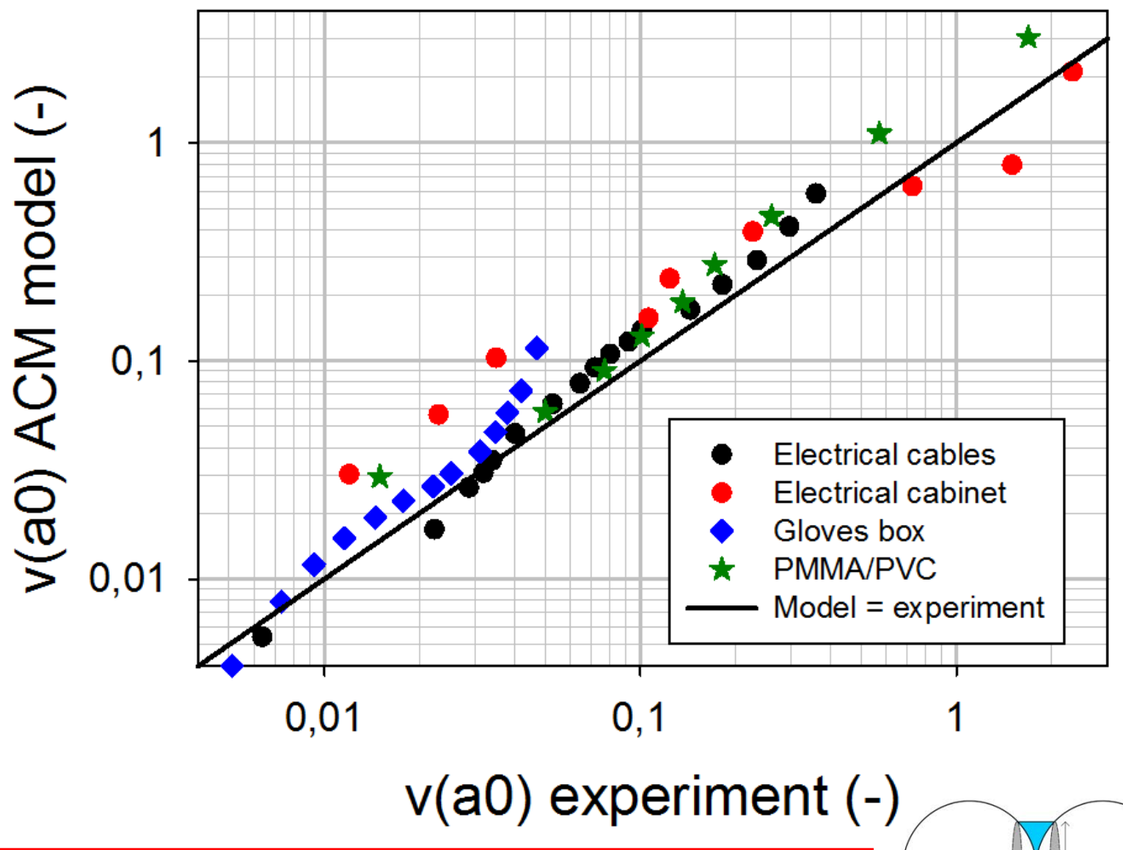
Fuel	Nature	D_{pp} (nm)	C_{ov}	BET (m^2/g)	Density (kg/m^3)	ε	T_C (%)	Compo	TEM image
PMMA / PVC (2/3 – 1/3)	Fractal	66	0.13	57,2	1260	0.985	25 - 35	C, O, Cl	
Electrical cabinet	Compact	222	-	144,2	1660	0.920	> 25	C, O, CL, Zn, Br, Pb Traces: P, Sb.	
Electrical cables	Fractal + Compact	68	0.05	144,2	1850	0.750	14	C, O, Cl, Rh, Pb, Na, Fe	
Gloves box	Fractal	42	0.14	43,8	1660	0.969	5 – 8	C, N, O, Fe, Cu, Si, S Traces: F, Na, Mg, P, Cl, K, Ca, V, Ti, Cr	

Water sorption isotherms

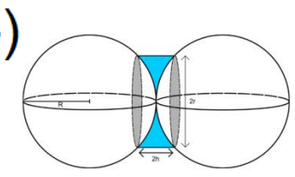


- PMMA/PVC has the highest affinity for water.
- No capillary condensation for gloves box.

Adsorption/condensation model [3]



$$v(a_0) = \frac{v_{mG}\, c_G\, a_0\, k}{(1 - k\, a_0)(1 + (c_G - 1)k\, a_0)} + Z\,\frac{\rho_l}{\rho_s}\left[3\left(\frac{h - t}{d_{pp}}\right)^2\left(1 - \frac{4\,(h - t)}{3\,d_{pp}}\right)\right]$$



Capillary condensation

- v_{mG}: quantity of sorbate needed to form a mono-layer (kg/kg)
- c_G, k: GAB constants (-)
- Z: coordination number (-)
- ρ_l, ρ_s: sorbate liquid and particle density (kg/m^3)
- h: meniscus demi-width (m)
- t: thickness of multimolecular layer (m)
- d_{PP}: particle diameter (m)

Conclusions

- Water sorption is strongly dependent on the fuel nature and fire conditions, further investigations are in progress.
- Water uptakes for fire related soot particles is significantly higher than those reported in the literature for soot particles produced by gaseous burners.
- Multi-molecular adsorption / condensation model is in reasonable agreement with experiments.

References:

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[3] Ribeyre, Q., Grévillot, G., Charvet, A., Vallières, C., & Thomas, D. (2014). Modelling of water adsorption–condensation isotherms on beds of nanoparticles. *Chemical Engineering Science*, *113*, 1–10.

[4] Popovicheva, O. B., Persiantseva, N. M., Tishkova, V., Shonija, N. K., & Zubareva, N. A. (2008). Quantification of water uptake by soot particles. *Environmental Research Letters*, *3*(2), 025009.