Clogging of Air Intake Filter Media by Mixture of Oil and Solid Dust

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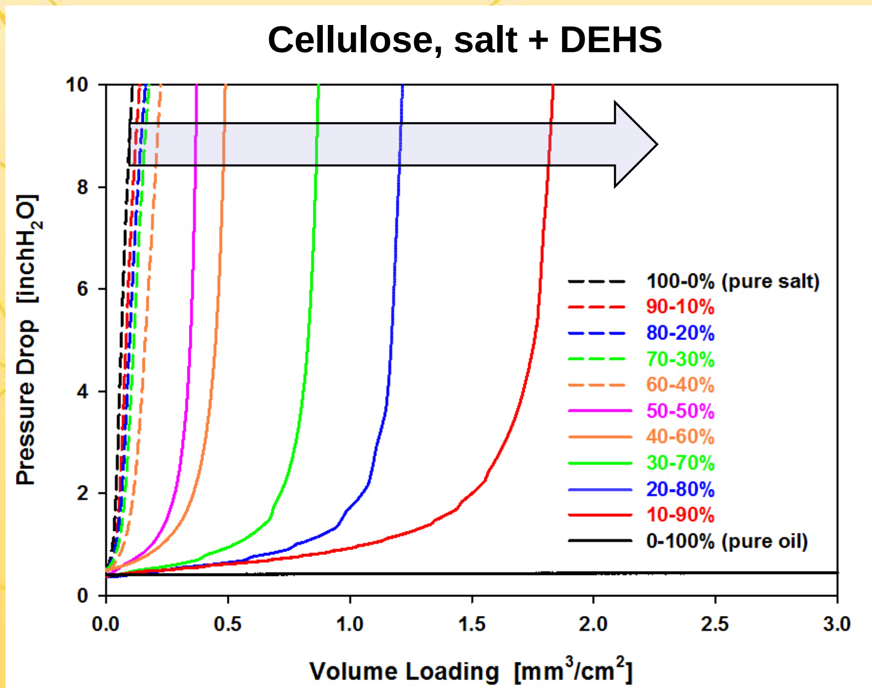
Introduction

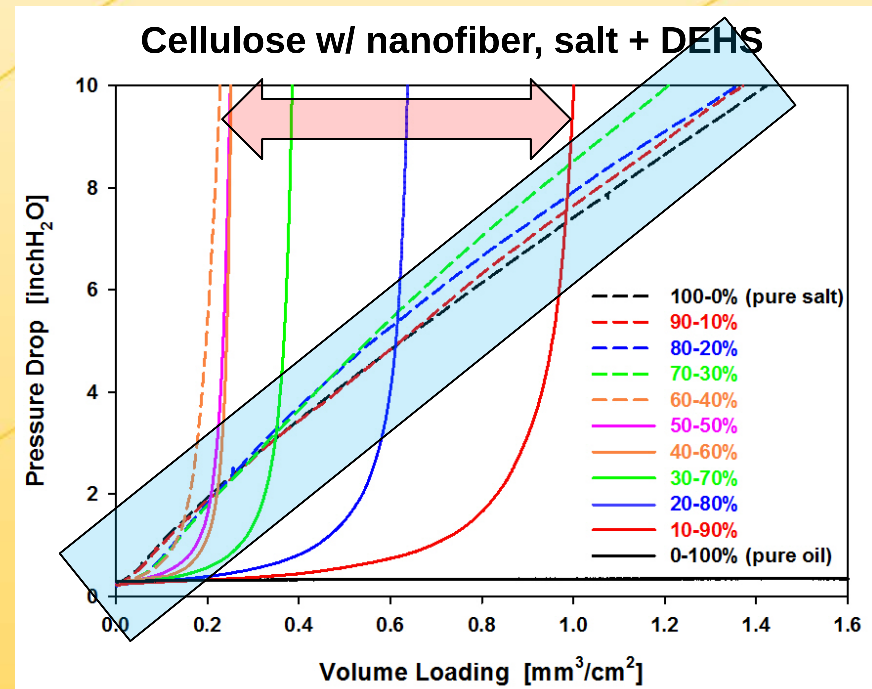
- Current air filter test standards employ pure solid (ISO dust, carbon black, cotton linter, NaCl, KCl, etc.) or pure liquid/oil (DEHS, PAO, etc.) as testing aerosol. Only pure solid particles are used to assess the filter holding capacity/lifetime or to condition/age the filter in standards.

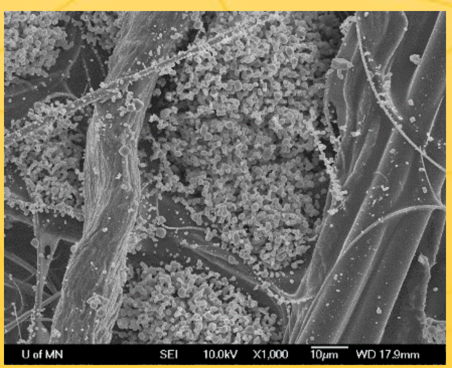
- Filters used in field may face aerosols from various sources with different physical states, e.g. mixtures of solid and liquid (oil) particles for filters used for colloid/mist removal, including cooking or oil handling application, offshore oil drilling platform, metal working fluid filtering, and etc.

- Although the clean filter efficiency may not be affected much by aerosol physical state, the filter loading and clogging behaviors can be much different.

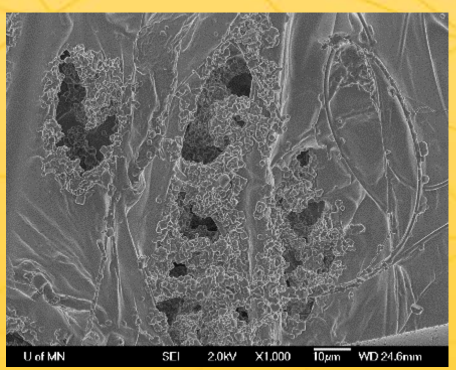
Introduction – Previous Results (I)



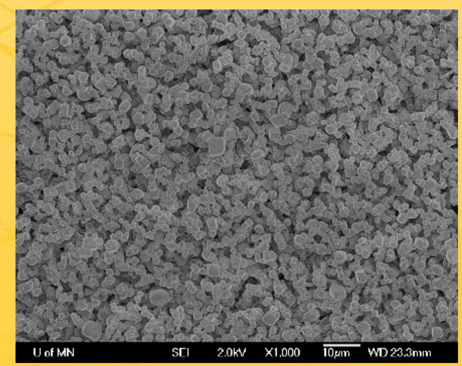




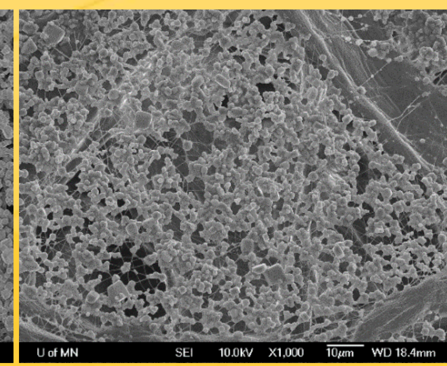
100% salt
depth loading



20% salt
depth loading



80% salt
surface loading



30% salt
film-clogging

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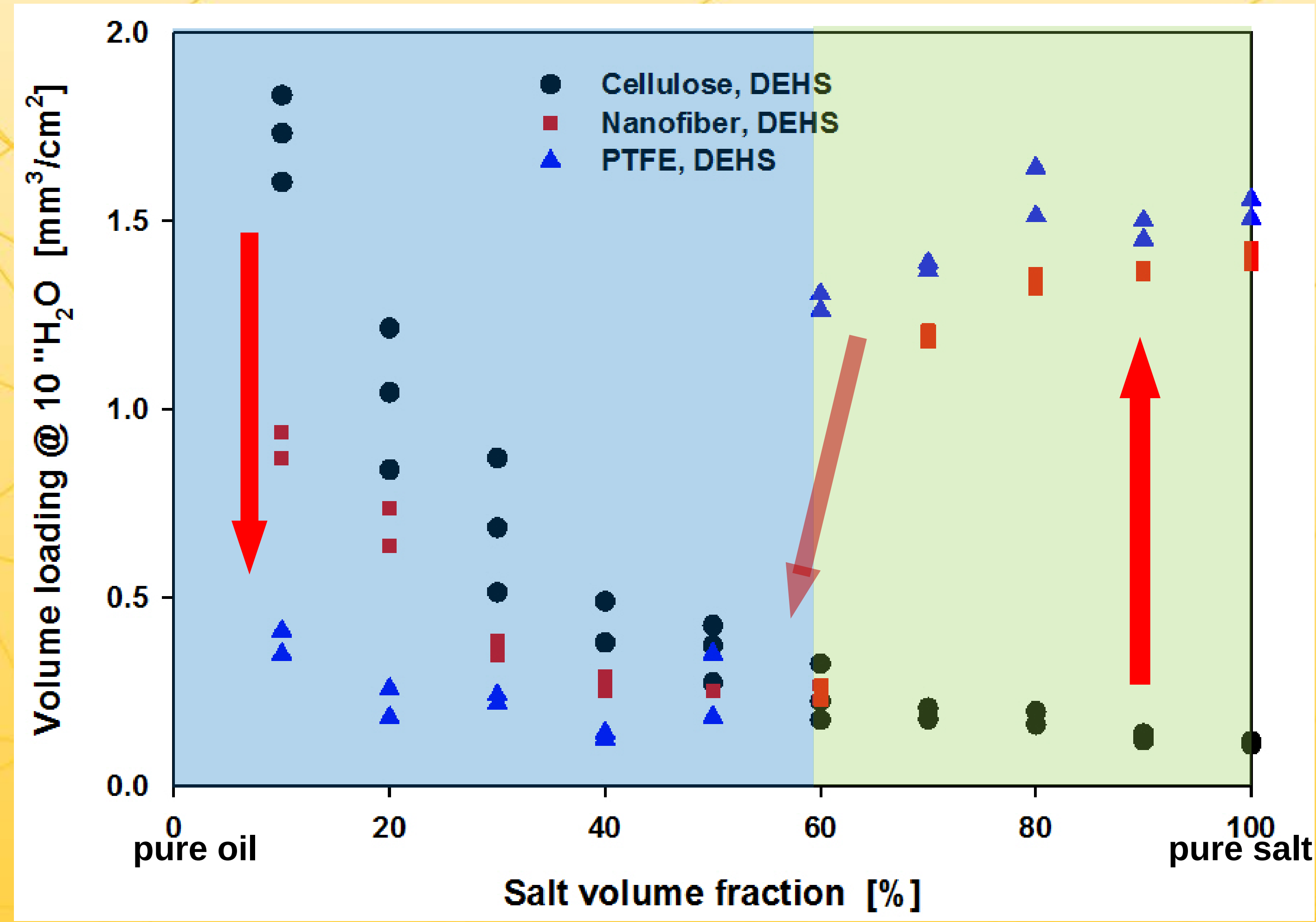
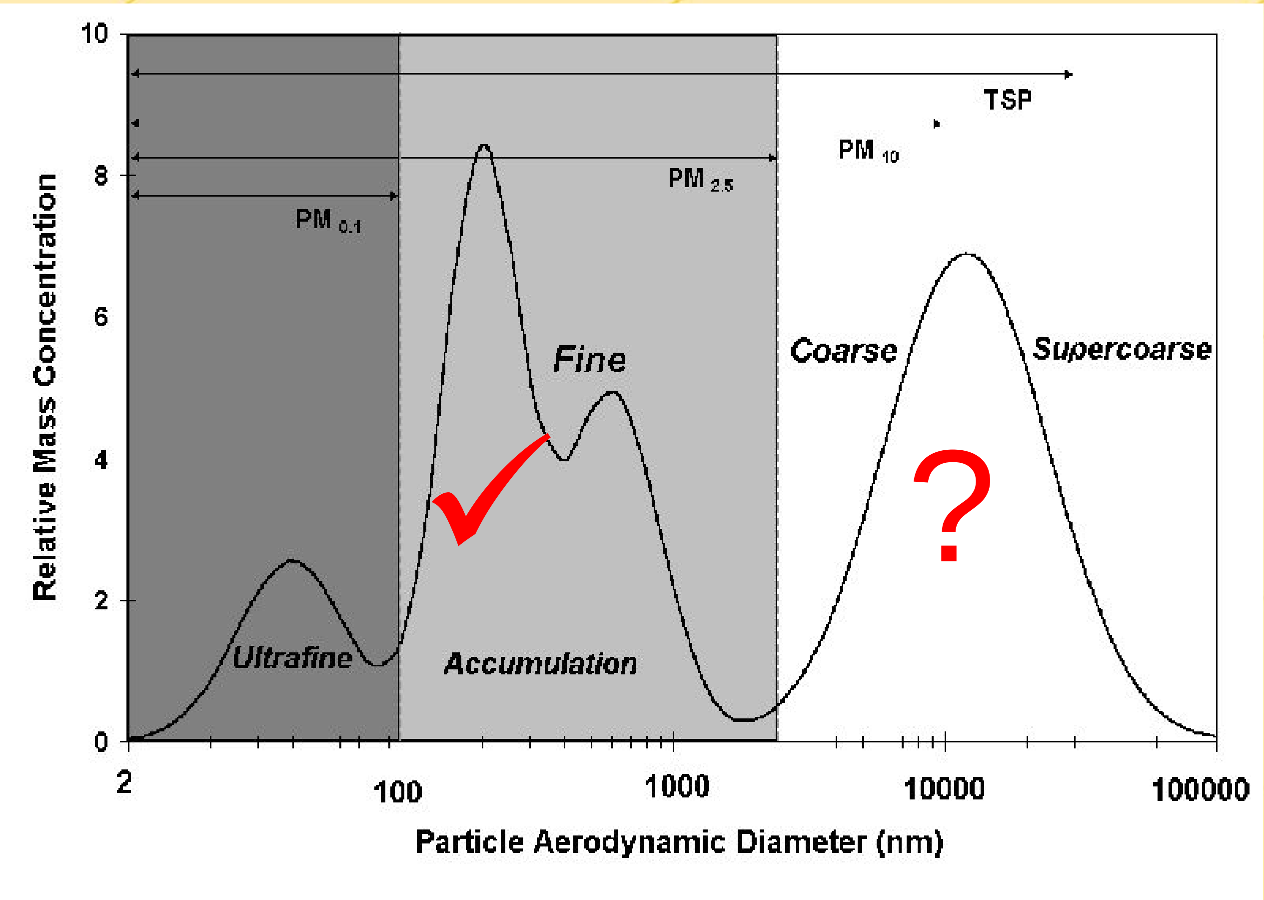
Introduction – Previous Results (II)



Introduction –
Atmospheric Aerosol Size Distribution



- How do the coarse mode **dust particles** interact with oil particles when loaded on air intake filter?

Test Variables

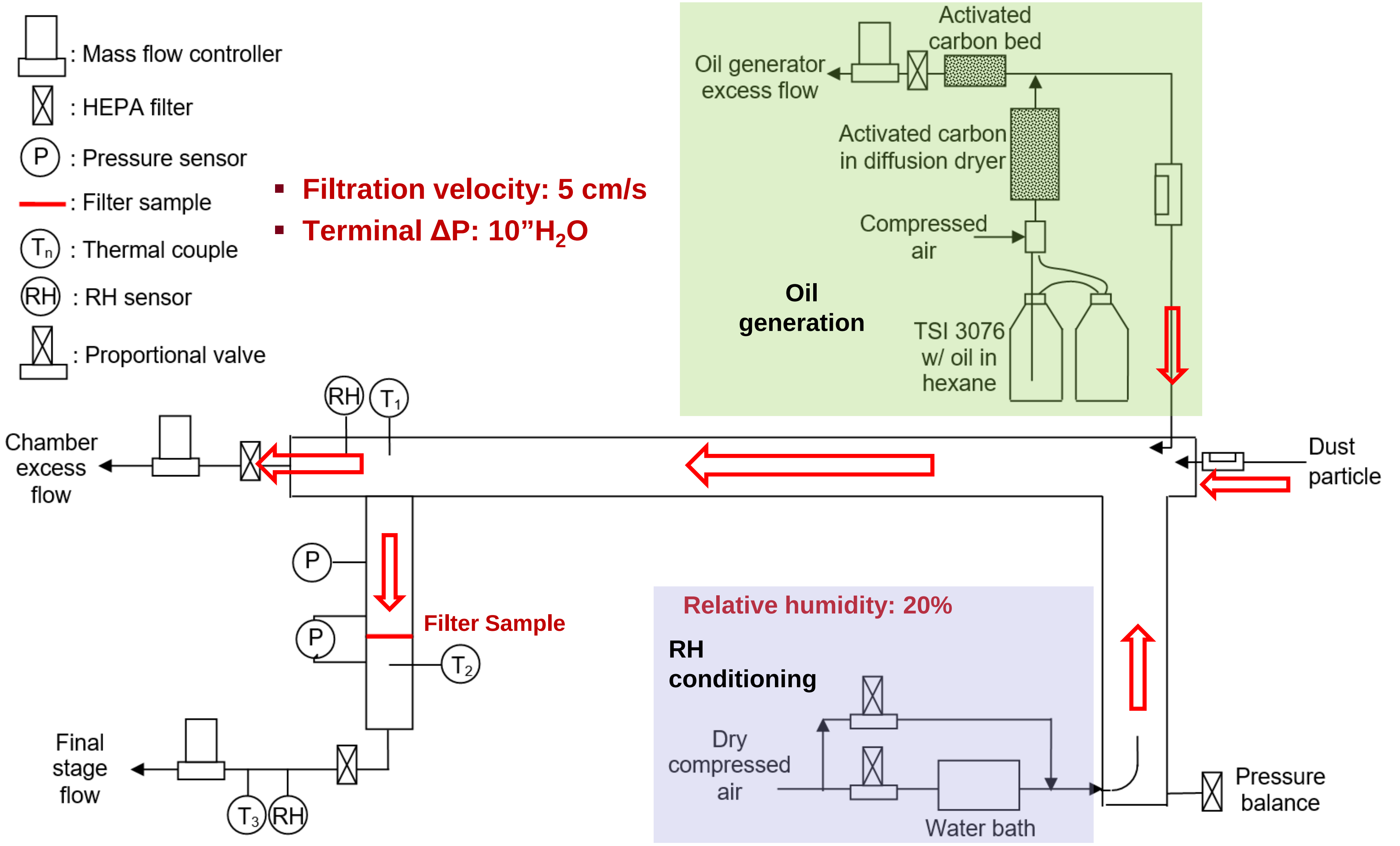
- Solid dusts
  - ISO 12103-1 Arizona Test Dust **A2 fine**
  - **0-5μm fraction** Arizona Test Dust (finer than A2)
- Properties of tested oils

Oil	Chemical name	Density [g/cc]	Viscosity @ 25 °C [10^{-3}Pa·s]	Surface tension [10^{-3}N/m]
DEHS	Dioctyl sebacate	0.912	24	32
N1400*	1-Decene, homopolymer, (PAO)	0.848	3000	32

* : viscosity standard oil from Cannon Instrument Company

- Solid-oil mixing ratio:
  - **Volume** fraction varied from 100%-0% (pure solid) to 0%-100% (pure oil), with 10% increment (e.g. solid fraction at 100%, 90%, 80%,…10%, 0%).

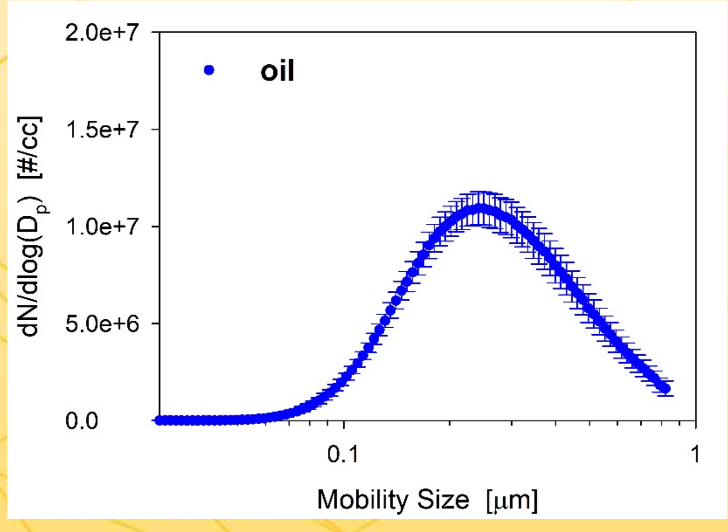
Schematic of Test Setup

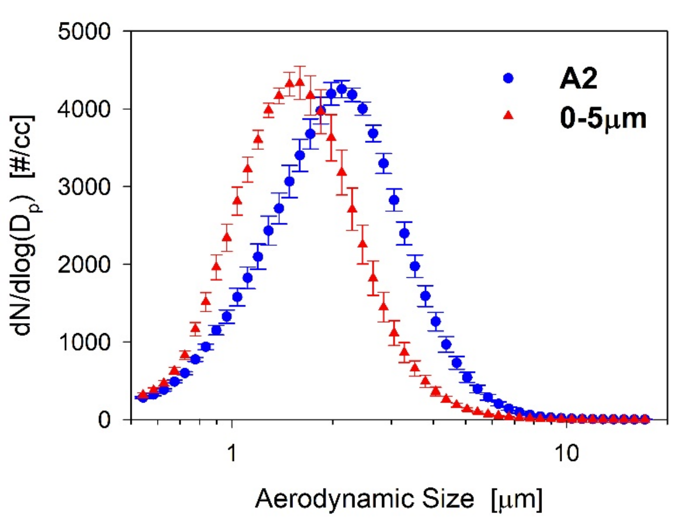


- **Filtration velocity: 5 cm/s**
- **Terminal ΔP: 10”H_2O**

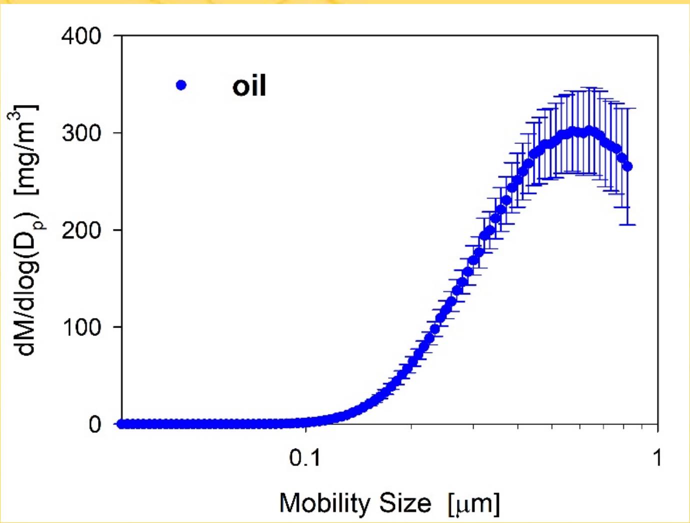
Distribution of Dust & Oil Particles

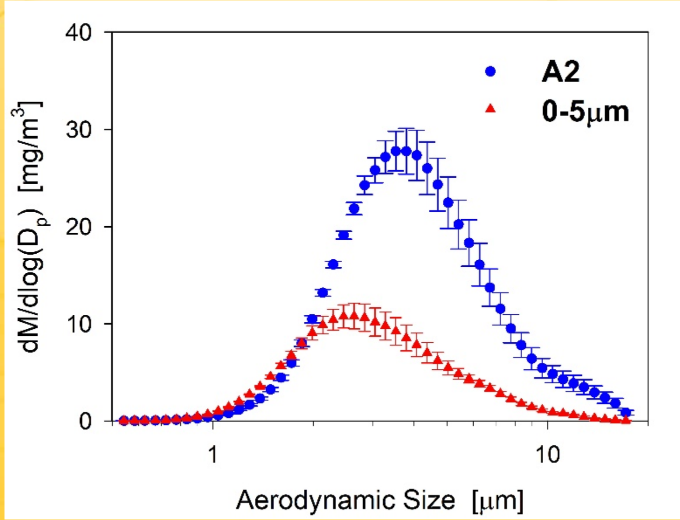
Number distribution





Mass distribution





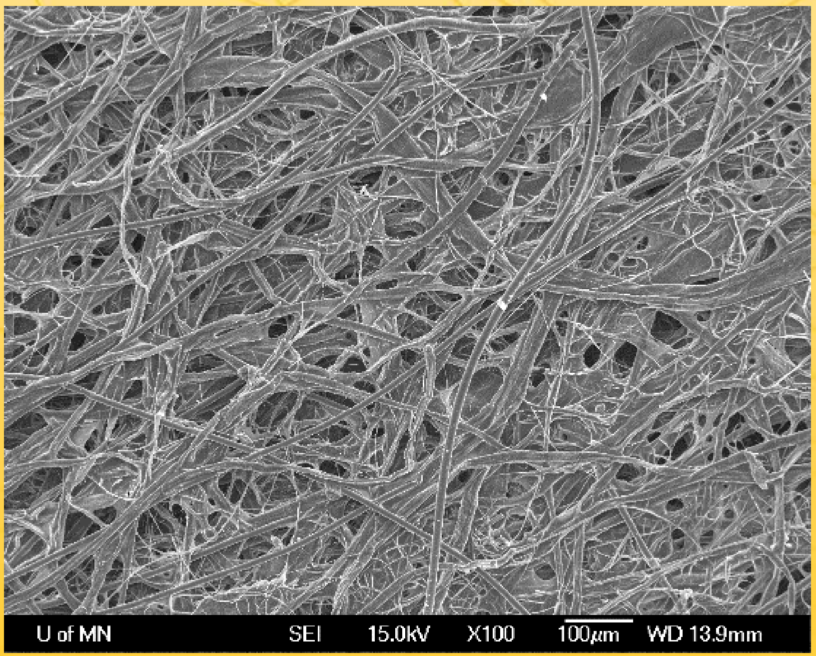
Dust concentration for loading test is higher than shown here.

Filter Media Tested

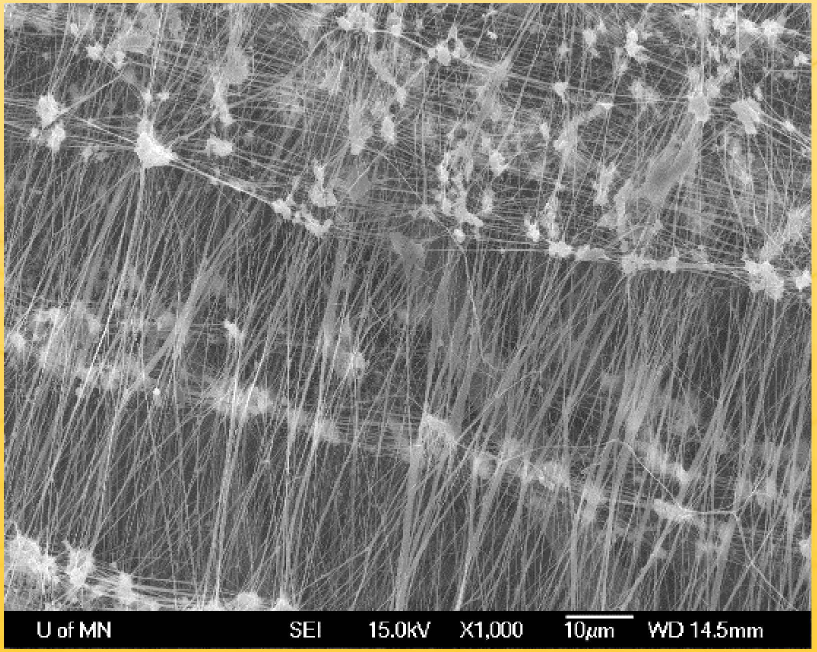
- Properties of tested filter media

Media	Material	Areal weight [g/m^2]	Efficiency rating	Initial ΔP @ 5 cm/s [inchH_2O]
A	cellulose	118±7	F7	0.35±0.08
B	PTFE	116±1	H11	0.29±0.01

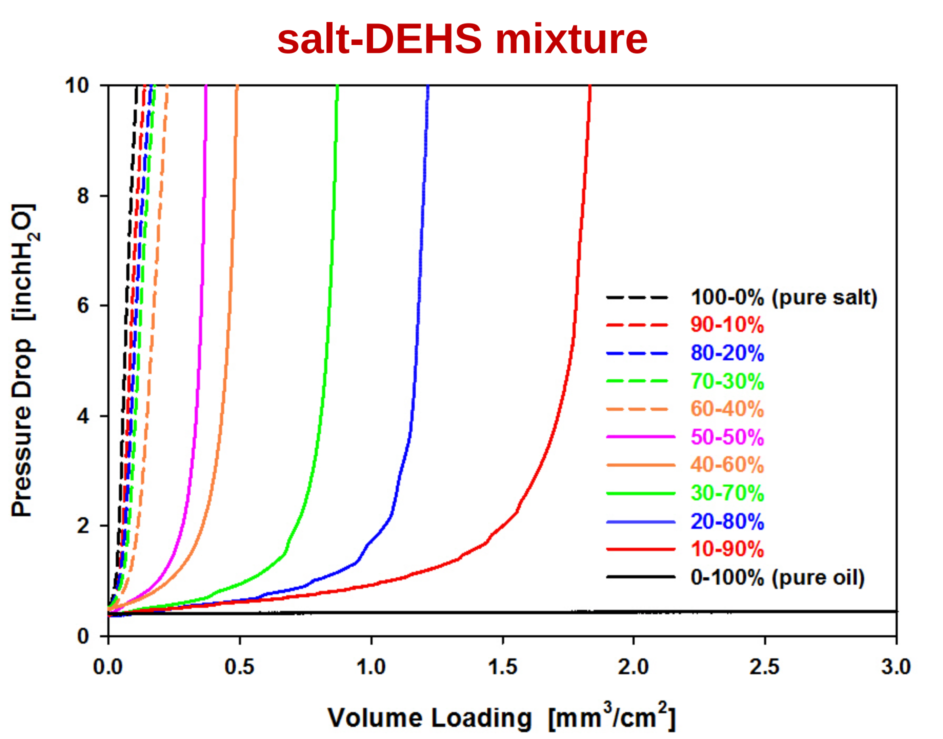
Media A: cellulose

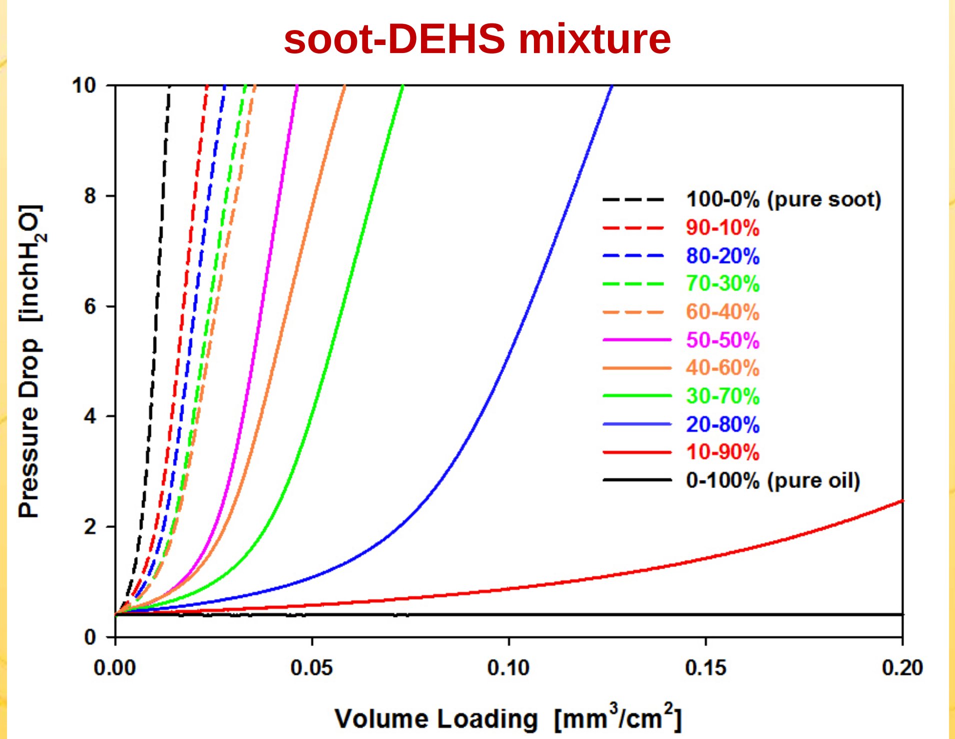


Media B: PTFE



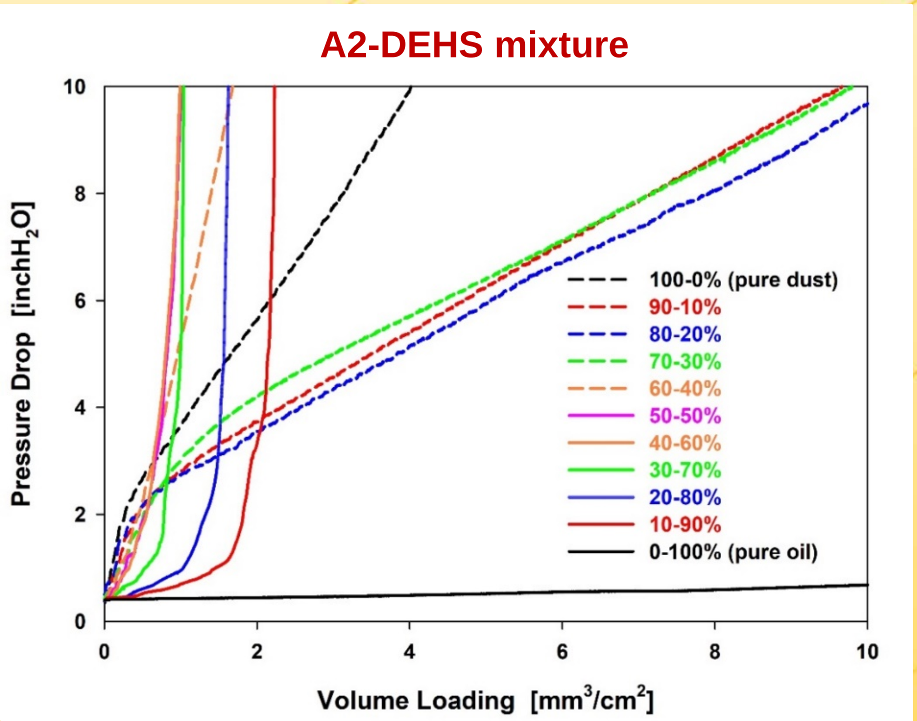
Results – Cellulose, Salt or Soot



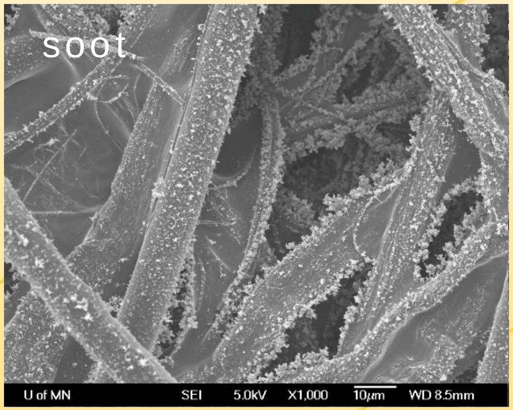


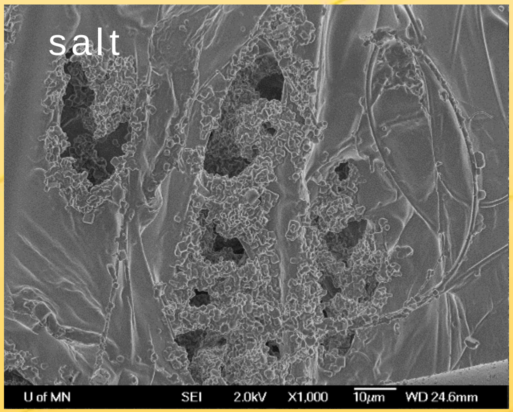
- For both salt and soot as solid particles, increasing oil fractions results in higher total volume loadings on cellulose media.
  - Oil spreads onto solid surface (media fiber or solid particles) along media thickness, without forming sticking-out dendrites;
  - Oil helps to break up solid dendrites due to surface tension while oil tends to soak into solid dendrites because of capillary effect.

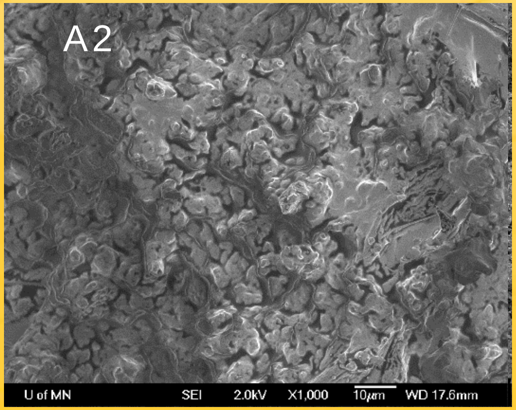
Results – Cellulose, A2



10% solid on cellulose

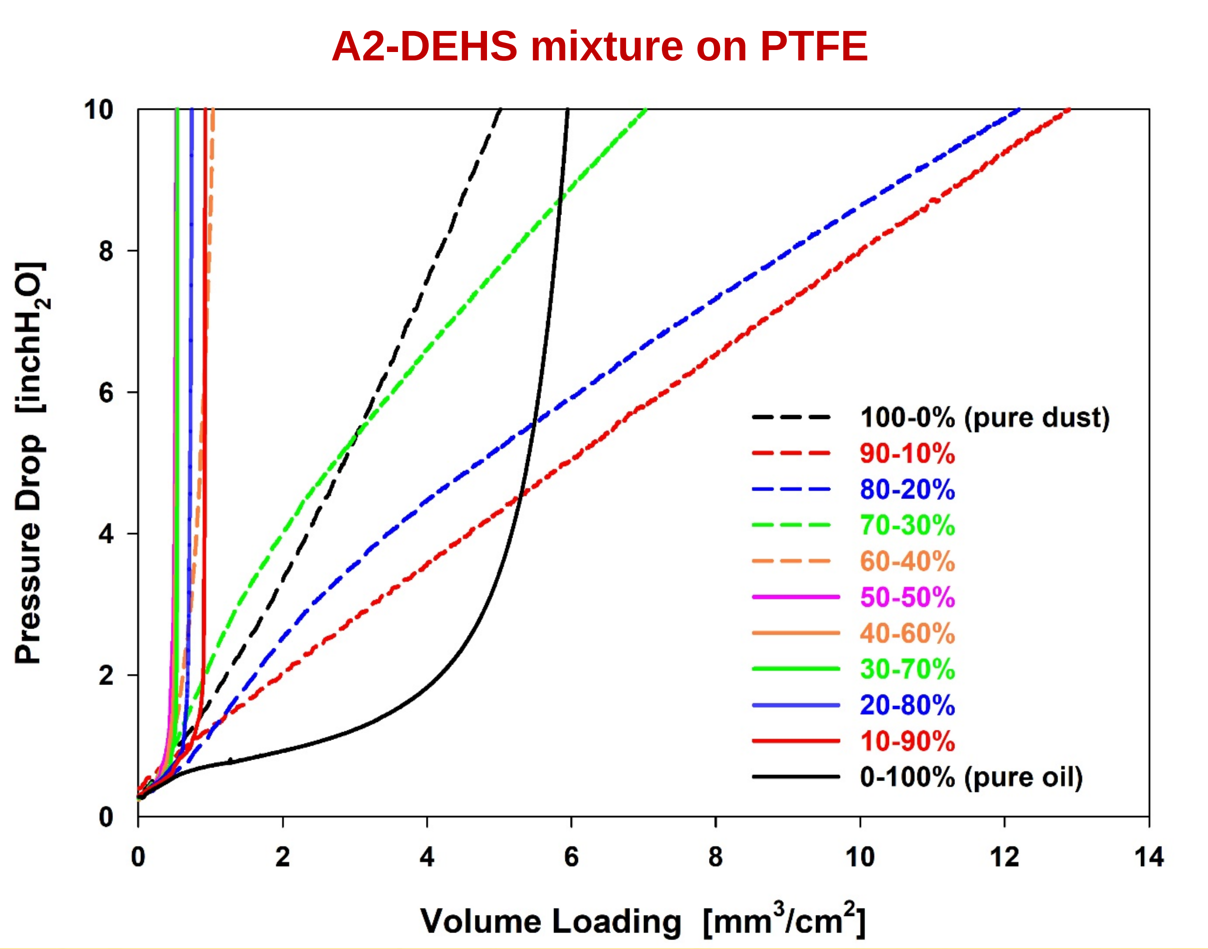




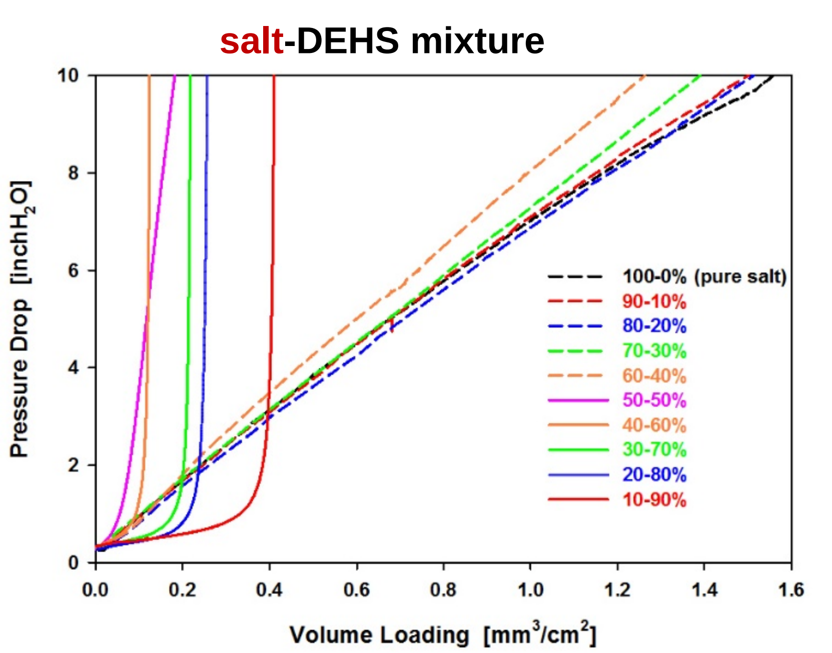


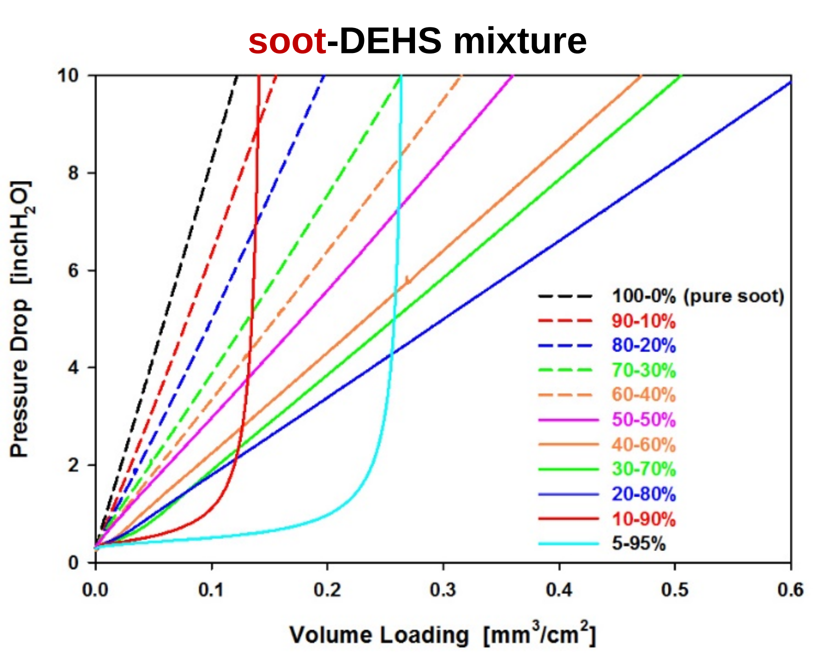
- Loading of A2 and DEHS mixtures on cellulose media has two clogging states, i.e., surface loading and film clogging, different from loadings by mixtures of oil with salt/soot particles:
  - Larger (relative to submicron salt/soot) dust particles penetrate less deeply into cellulose media, quickly forms cake on media surface, extending media lifetime at high solid fractions;
  - Relatively lower porosity and stronger (do not break up) dust dendrite serves as skeleton for oil to spread on to form oil film, which clogs media quickly at high oil fractions.

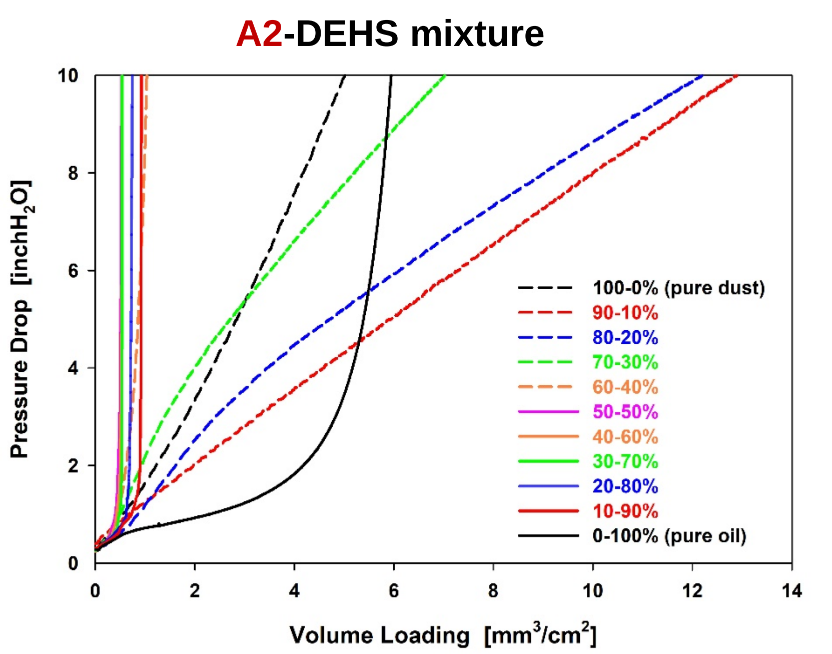
Results – PTFE, A2



Results – PTFE, Salt vs. Soot vs. A2







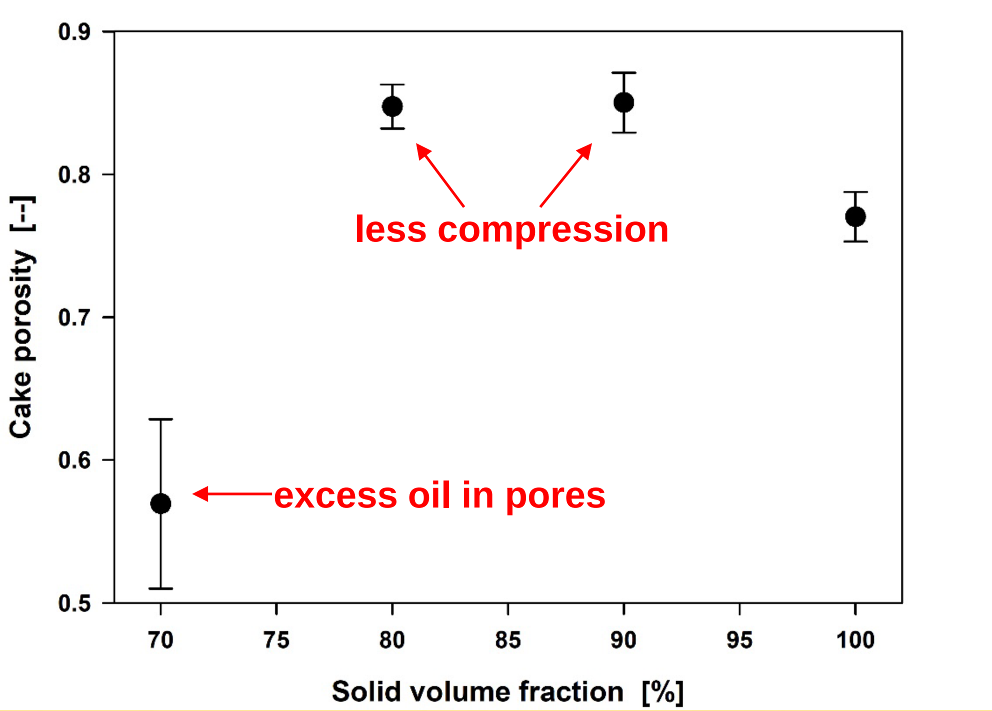
- Similar trends of transition from surface loading to film clogging was found for all three types of solid particles. But differences exist:
  - Transition from surface loading to film clogging happens earlier (at lower oil fraction), when porosity of solid cake is lower. (dust < salt < soot)
  - Slope change within cake loading region are different among the three solid cases.

PTFE Media – Cake Porosity at High Solid Fractions

- The thickness of A2-oil cake layer was measured using a video-enhanced microscope (VEM). The cake porosity was further calculated knowing cake mass and thickness.

$$\varepsilon = 1 - \frac{M}{A\rho_p th}$$

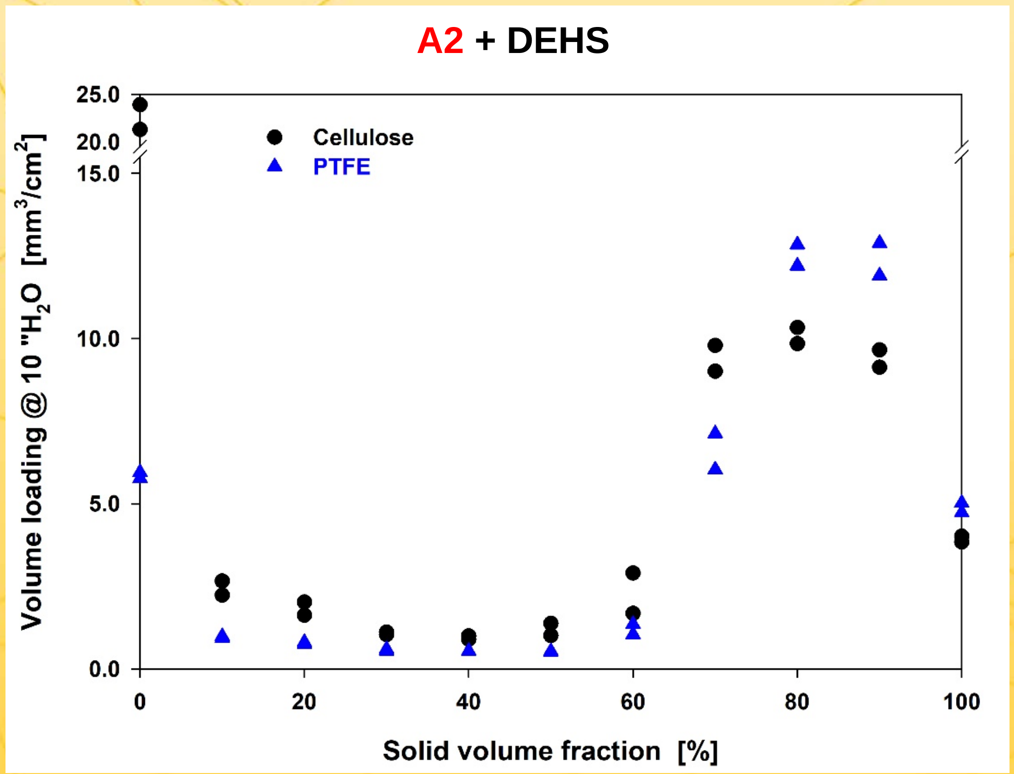
ε : cake porosity
th : cake thickness
M : cake mass
A : filtration area
ρ_p : average density of dust-oil mixture

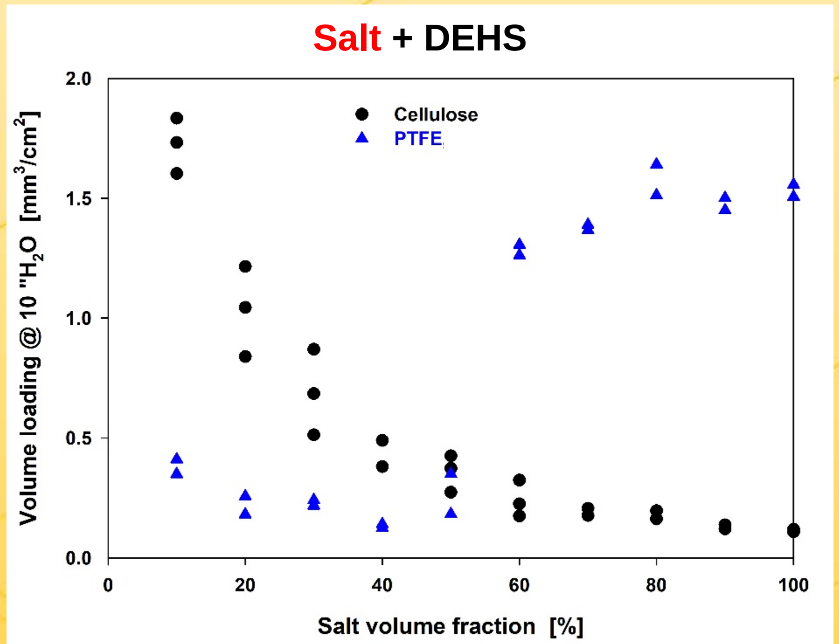


- Slight amount of oil increases porosity of the dust-oil cake layer, by coating on dust surface and increasing friction force between dust particles. Consequently cake becomes less compressed and more permeable.

- Excess oil (30% or higher) soaks into dust dendrite, reduces cake porosity, blocks micro-pores, results in film-clogging loading pattern.

Holding Capacity of A2-DEHS Mixtures





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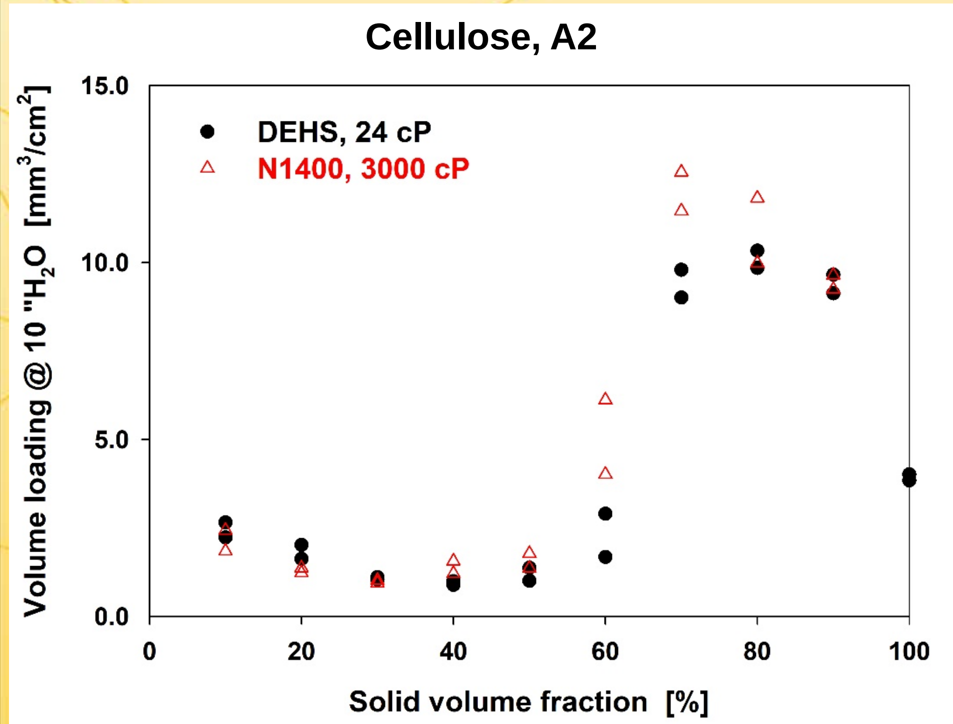
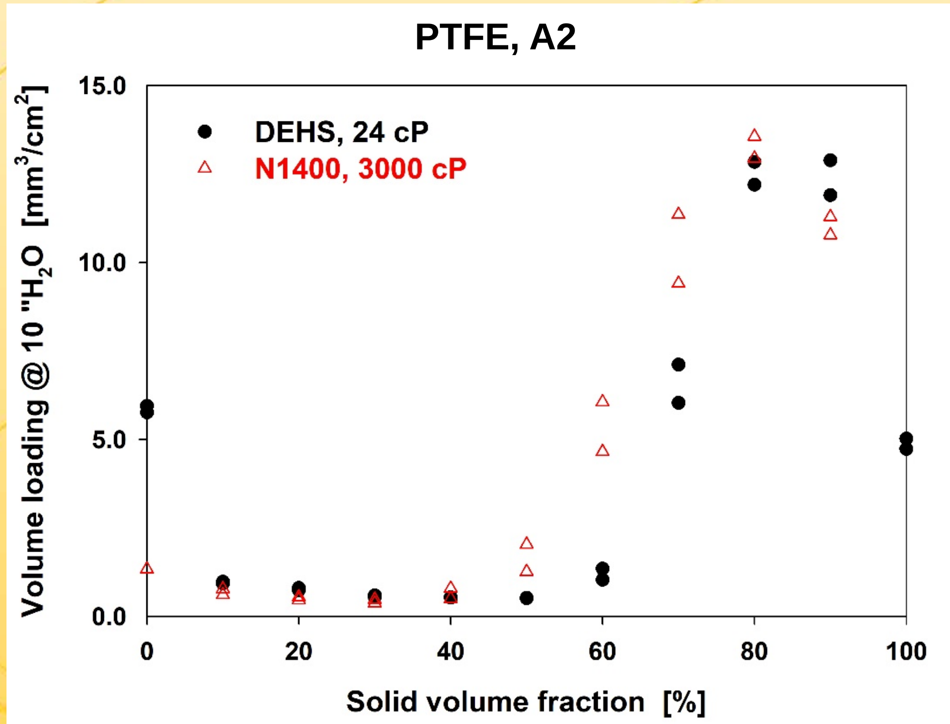
Effect of Oil Viscosity



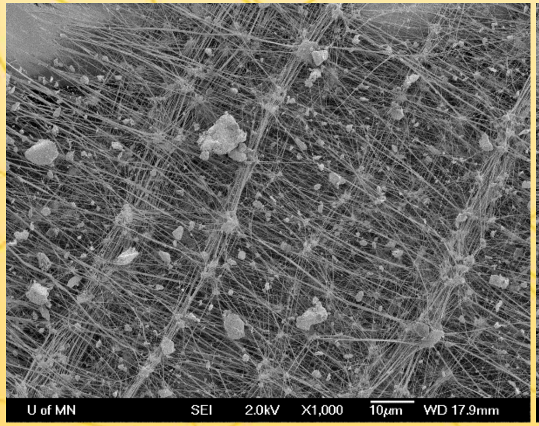


- At current total aerosol concentration (250-450 mm^3/m^3), viscosity of oil particles has very minor effect on clogging pattern and holding capacity.
  - High viscosity oil might be associated with a later onset of clogging pattern transition, probably due to its difficulty in migrating into pores between solid particles.
  - Effect of oil viscosity is expected to be pronounced if tested at much lower aerosol concentration, which also represents real situation better. However, maintaining a stable of dust generation is challenging at lower throughput.

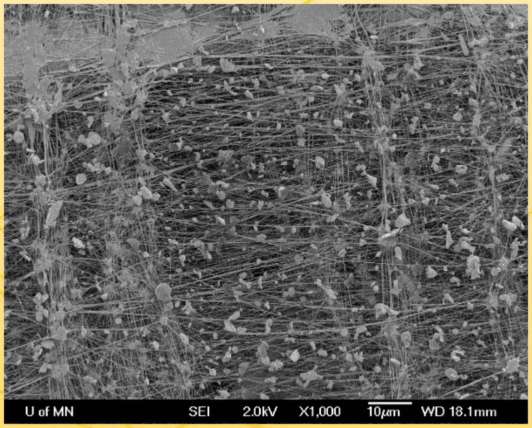
Dust Size Effect on Pure Solid Loading

SEMs of lightly loaded media:

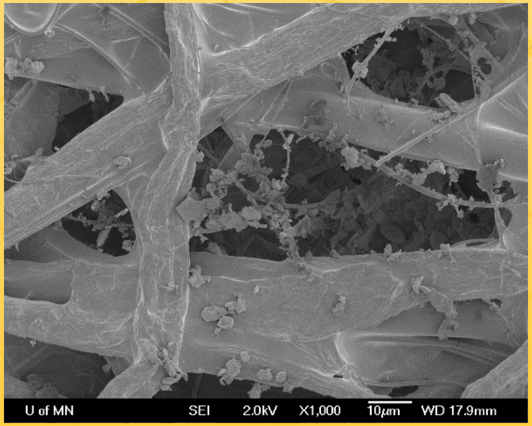
A2 dust on PTFE



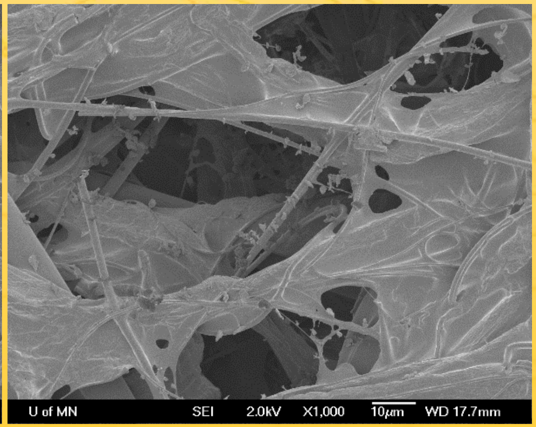
0-5µm dust on PTFE

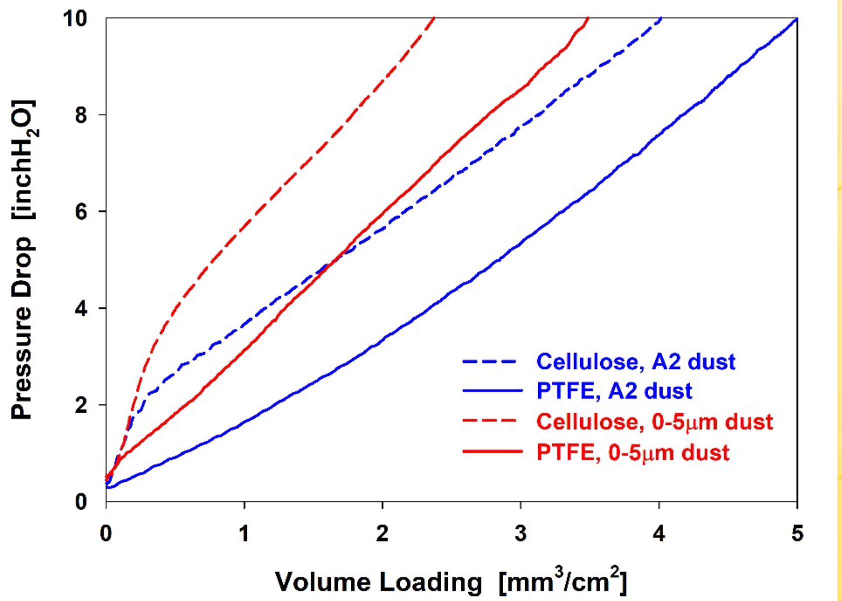


A2 dust on cellulose



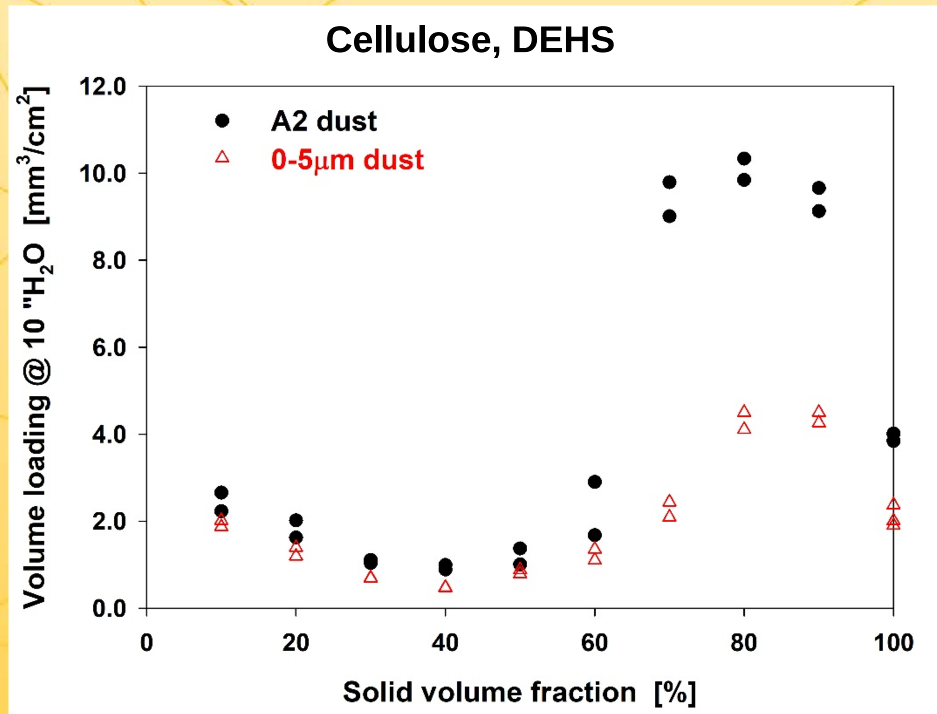
0-5µm dust on cellulose

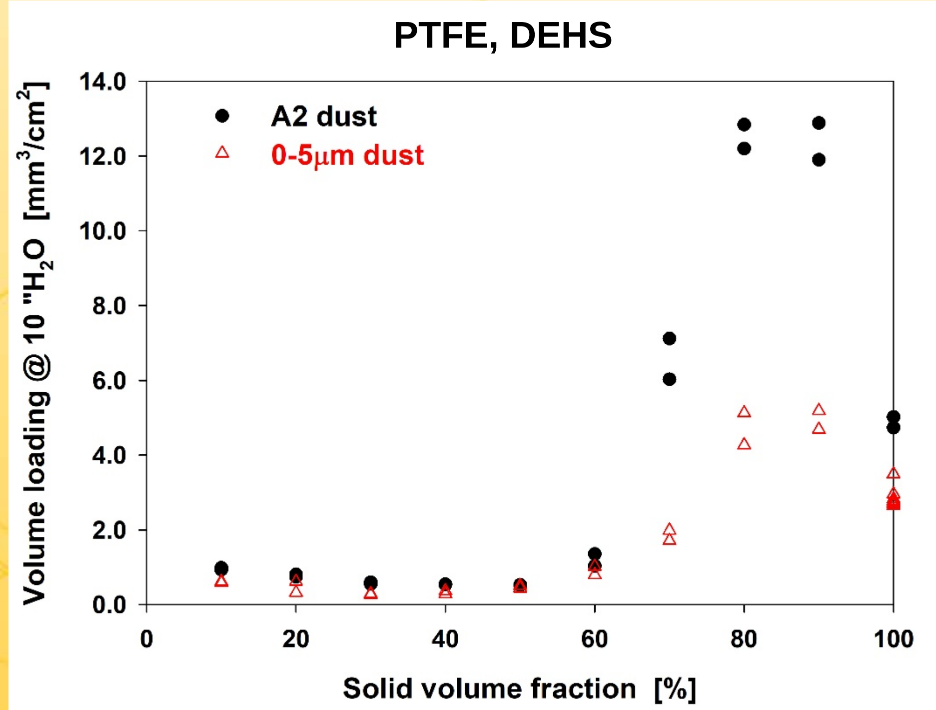




- 0-5µm dust has steeper slope and lower volume loading.
  - ➢ Finer dust size provides more surface area to introduce friction force to the flow;
  - ➢ Finer dusts penetrate into deep layer of cellulose media, resulting in faster initial loading.

Holding Capacity of 0-5µm dust & DEHS mixtures





Summary

Solid particle type	cellulose	nanofiber & PTFE
submicron salt	➢ depth loading at all mixing ratio; ➢ oil contributes less in forming dendrite.	➢ surface loading at high solid fraction; ➢ film clogging at high oil fraction (>~50%).
combustion soot	➢ depth loading at all mixing ratio; ➢ oil breaks up dendrites by surface tension while soaking into porous dendrites.	➢ surface loading at high and medium solid fraction; ➢ film clogging at very high oil fraction (>80%).
coarse dust	➢ surface loading at high solid fraction; ➢ film clogging at high oil fraction (>~50%).	➢ surface loading at high solid fraction; ➢ film clogging at high oil fraction (>~40%).

Factor	Effect
Oil viscosity	➢ Oil viscosity has negligible effect at laboratory loading rate (~1 g/m^3); ➢ Difference in drainage rate of different oil viscosities is expected, but the experiment test is impeded by stability of dust feeding at low concentration.
Dust size	➢ Finer dusts penetrate more into deeper area of cellulose media, resulting in longer depth/transition loading with more rapid pressure drop increase; ➢ Loading pattern transition happens at almost same mixing ratio between A2 and 0-5µm dust.