

# Characterization of Fouling with Hygroscopic and Non-hygroscopic Aerosols in Composite Polymer Membranes for Water Vapor Transport Applications

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## Overview

Composite membranes using a thin vapor-permeable polymer layer over a structural substrate are used in gas dehydration, food-packaging, and humidity control of indoor spaces. One application of such membranes is in enthalpy exchanger cores used in Energy Recovery Ventilators (ERV) of building HVAC systems.

There are many studies of membrane fouling from liquids (e.g. reverse osmosis [1]) and gases (e.g. micro- and ultra-filtration [2]) but we have found only one study for composite membranes in HVAC-relevant conditions. Charles & Johnson [3] characterized the air-side particulate fouling of a hollow-fiber membrane during a membrane evaporative cooling process. They found significant biological growth, but only minor impacts on water vapor transfer – not surprising because the fouling was from clean air (~3000 particles/cc) over only 120 hours.

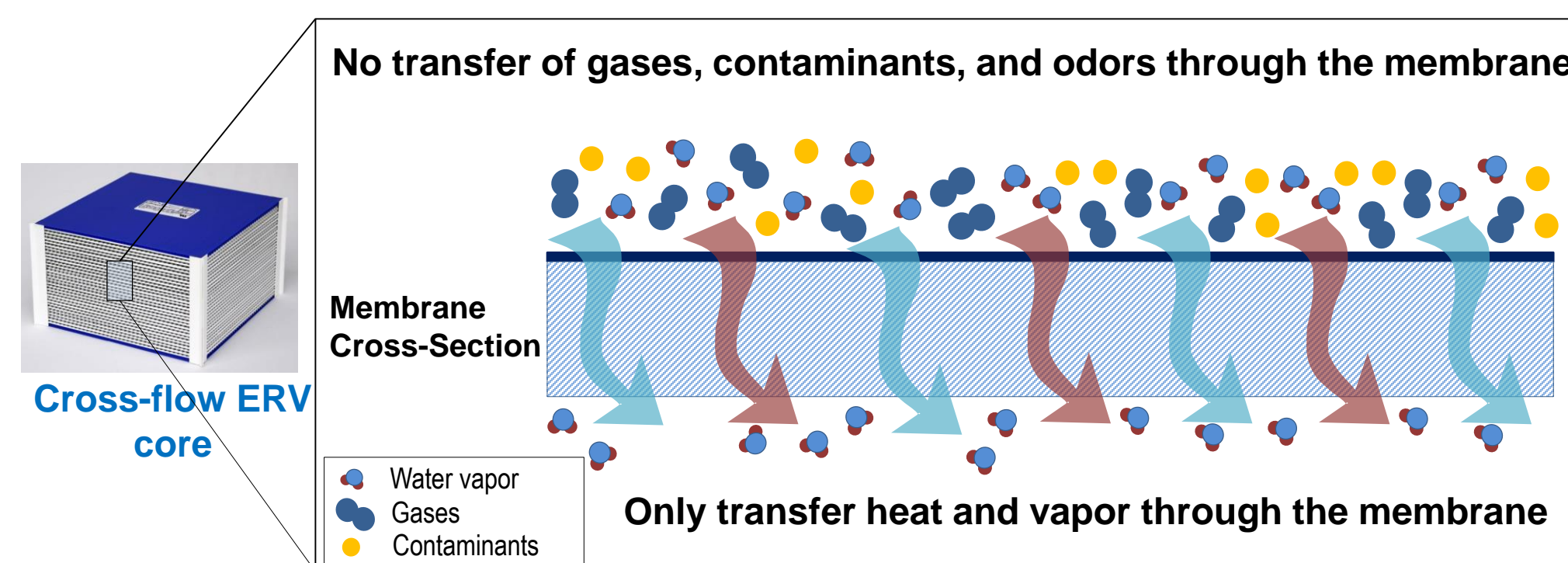


Figure 1: Ideal Membranes for building ERV application

In our work, the impact of accelerated exposure to air pollution on the water vapor flux through commercial membrane media is investigated to develop an understating of potential air-side particulate fouling mechanisms and resulted performance degradation during membrane lifetime in the field.

## Experimental Methodology

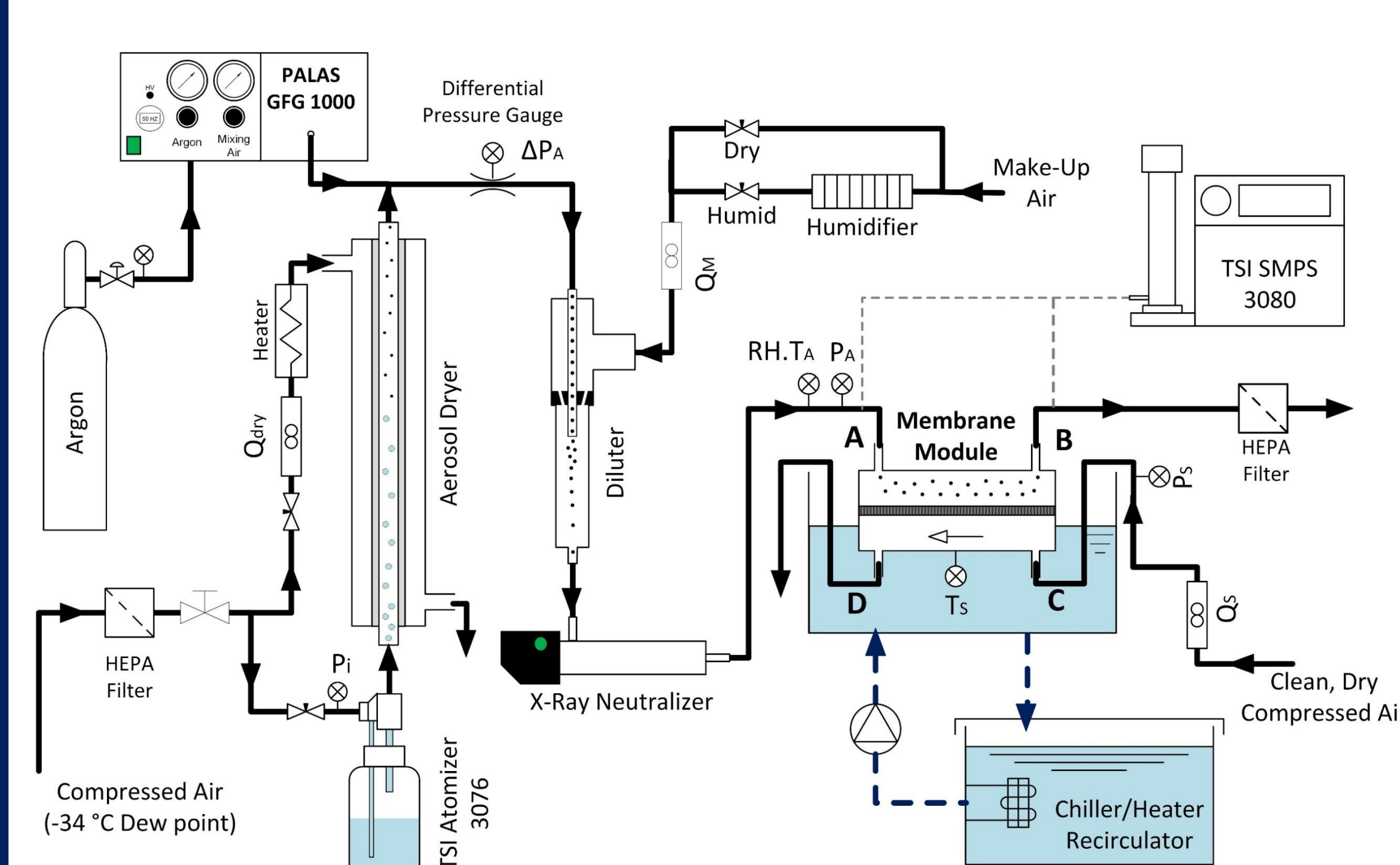


Figure 2: Experimental schematic

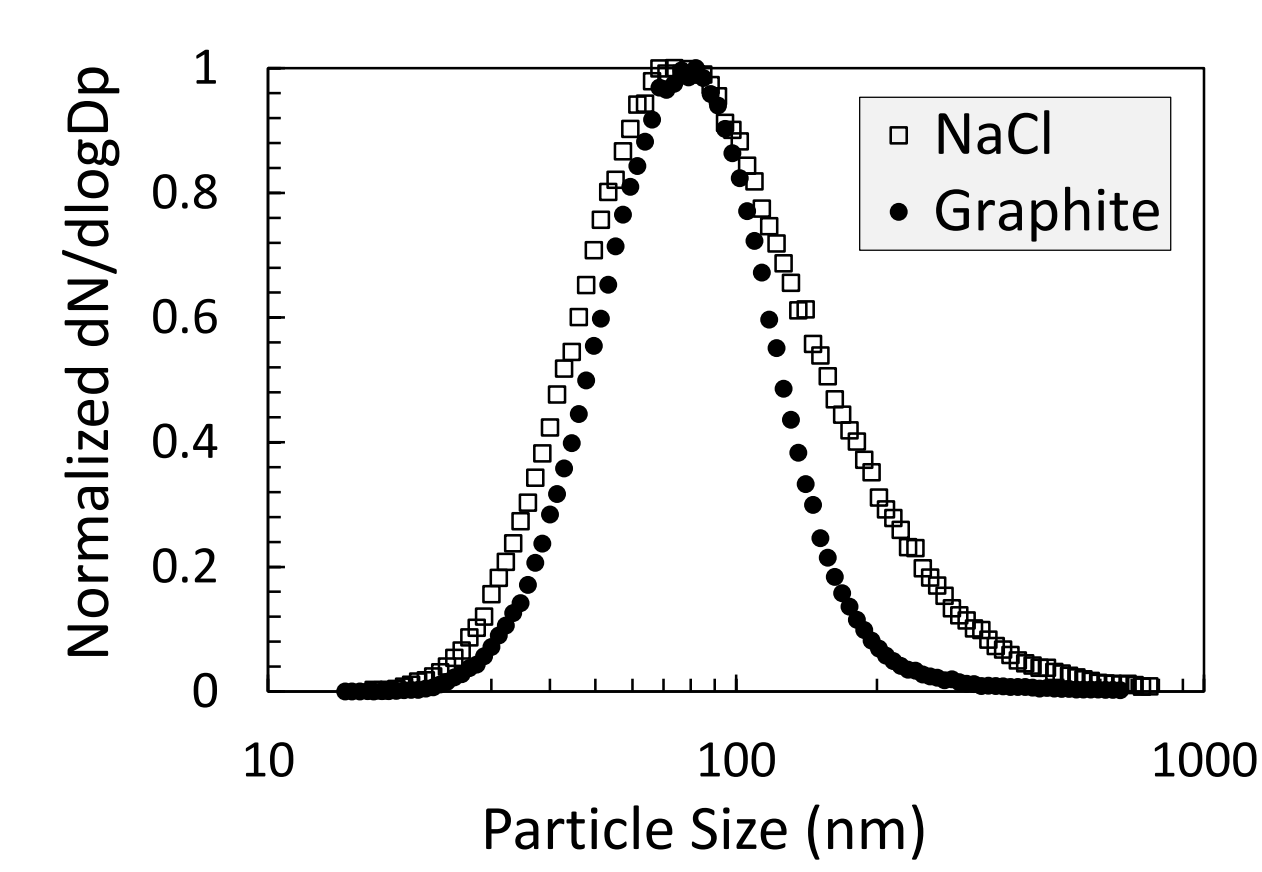


Figure 3: Particle mobility size distribution

- Two aerosol types:
  - Hygroscopic salt (NaCl, Dg=88nm) from TSI 3076 atomizer
  - Non-hygroscopic soot-like spark-generated graphite (SGG) (Dg=82nm) from a PALAS GFG 1000
- Upstream/downstream size distributions by TSI SMPS 3080 (used in deposition calculations)
- Membrane surface charge removed by immersion for 30 minutes in isopropyl alcohol
- Membrane samples are placed inside a counter-flow test module (active area of 456 mm<sup>2</sup>) that passes two air streams on opposing sides of the membrane:
  - A-to-B: particle-laden airstream flowing in a circuit that allows for control of the size and concentration of aerosol, the RH and the flowrate
  - C-to-D: sweep dry, HEPA-filtered airstream that allows control of the flowrate and temperature.
- Cumulative exposure is approximately that of one year of exposure in a heavily polluted environment.

### Loading conditions:

- Dry loading with RH<20% for the aerosol airstream
- Wet loading cycles in which dry loaded samples are exposed to intermittent humid conditions (RH~75%) leading to surface condensation

### Performance Testing of Membranes includes [5]:

- Particle deposition fraction measurement
- Water Vapor flux (pre- and post-loading)
- Pressurized air crossover leak rate (at 1 PSI)

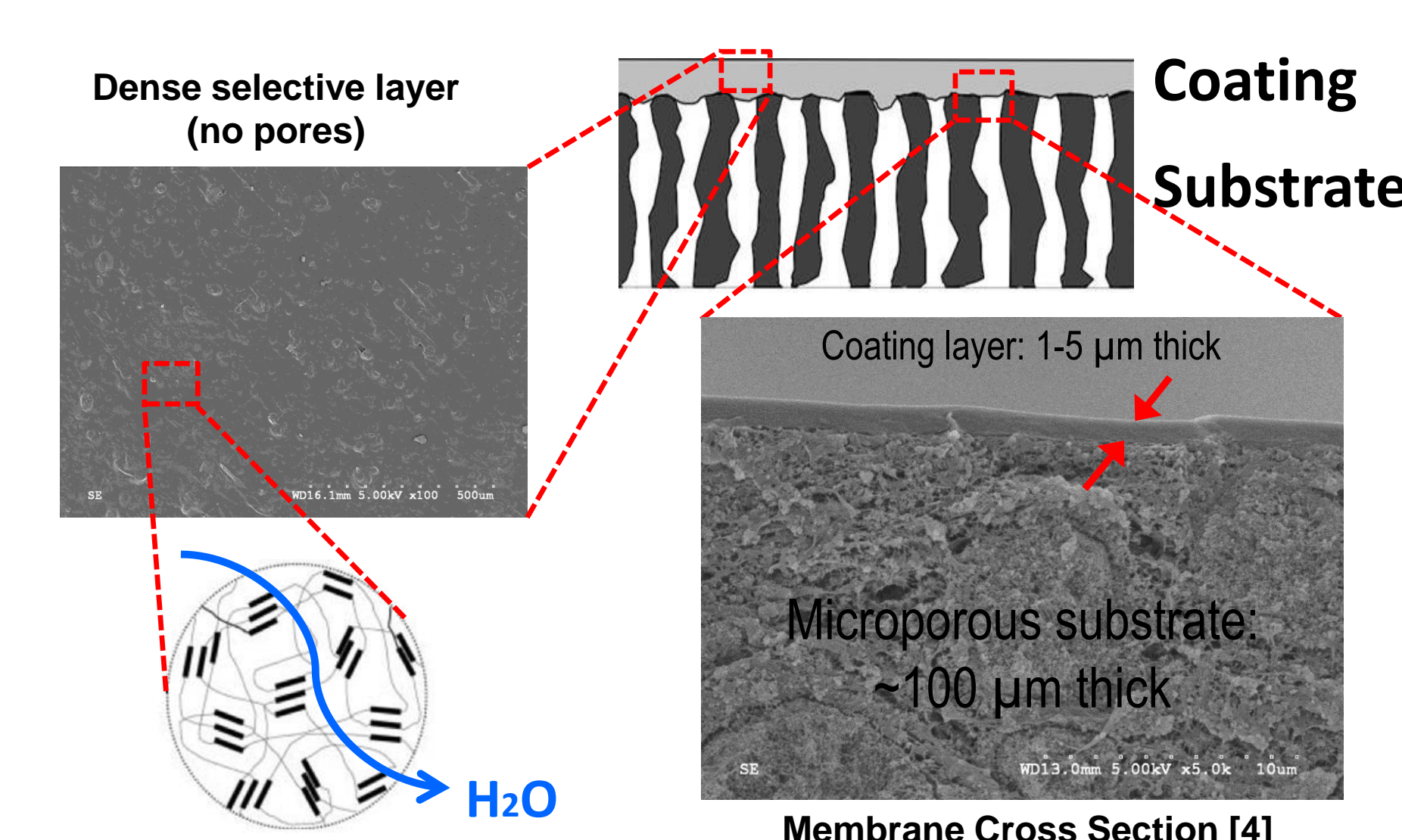


Figure 4: Composite Polymer membranes

- Composite membranes are composed of a dense polymer film coated on the surface of a porous polymer substrate.
- The dense coating layer (<10µm) provides a water-vapor-selective barrier and the porous substrate layer provides the mechanical strength of the membrane.
- The two sides of the membrane are referred to as 'coated' and 'uncoated' sides.

Table 1: Properties of membrane samples

Membrane	Coating Material	Substrate	Thickness (µm)	Water Vapor Flux at 50°C (kg/m <sup>2</sup> /day)
MA	A hydrophilic PEO-based block co-polymer film	Coated on a hydrophobic PE-based substrate	105-115	22 ± 4
MB	A hydrophilic cellulosic-based polymer film	Coated on a hydrophobic PP substrate	35-50	30 ± 3

## Particle Deposition on Membrane Surfaces

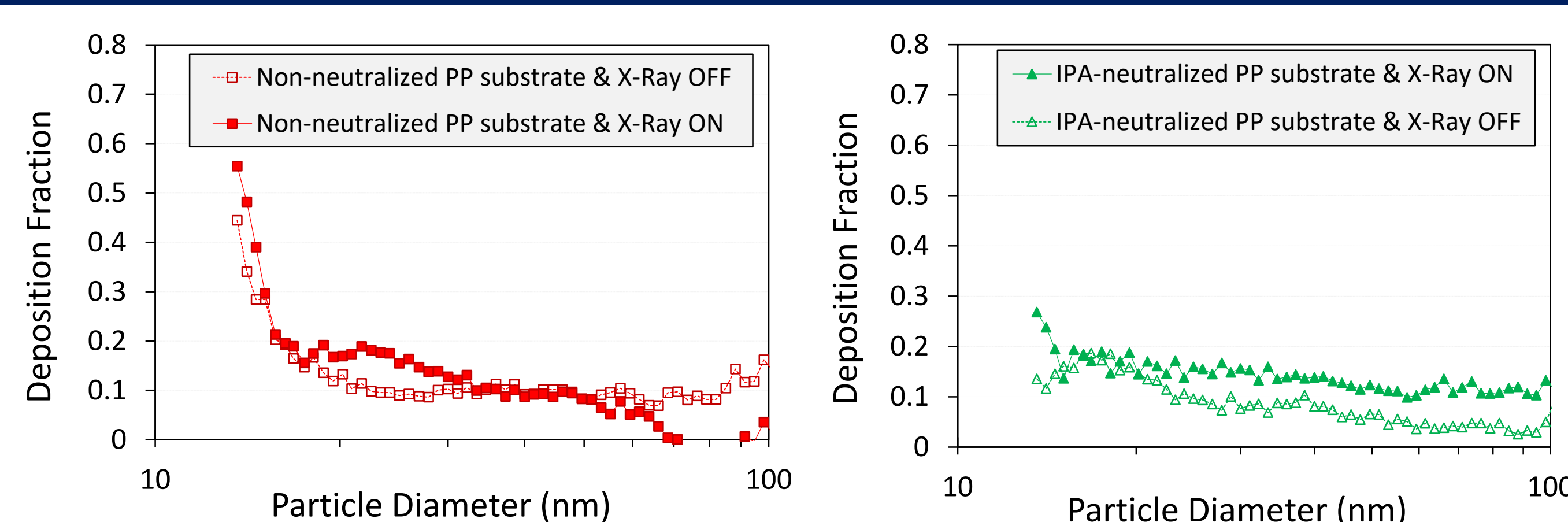


Figure 5: Impact of particle and surface charges on particle deposition

- The effects of particle charge distribution, number concentration, temperature-gradient (Thermophoresis), and membrane surface on the rate of particle deposition were investigated using a TSI SMPS 3080.

- Neutralization of surface charge by IPA reduces deposition of the smallest particles.

- Aerosol particles neutralized with a soft x-Ray neutralizer (TSI 3088) showed a tendency to form uniform, compact deposit layers leading to cake layer formation on membrane surfaces and flux reductions of up to 5% of the clean membrane value.

- Although the state of the aerosol and surface charges influence the deposition fraction and the deposit morphology, it is shown through vapor flux measurements that they have little direct influence on the degradation of membrane permeability.

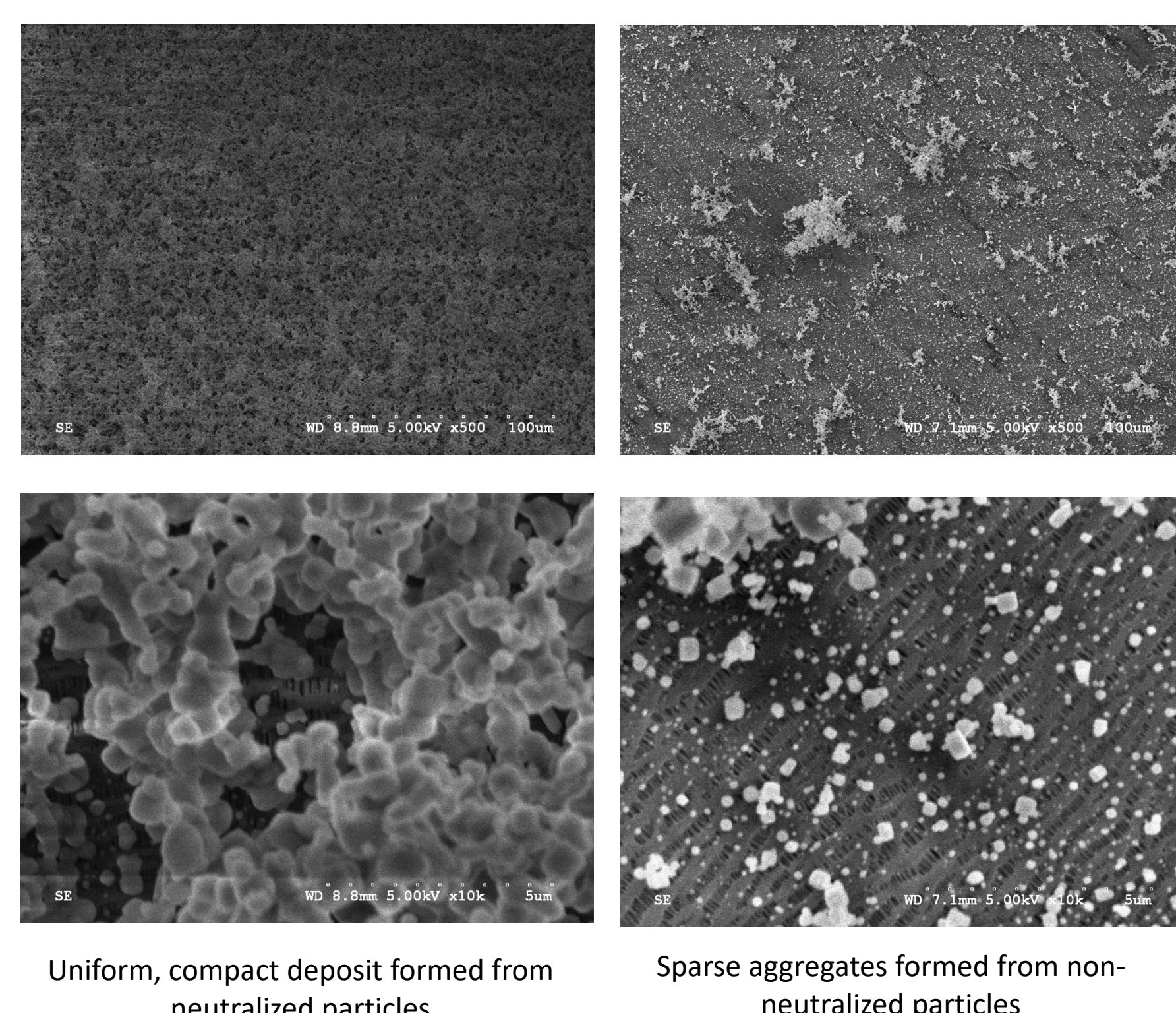


Figure 6: Effect of particle charge on deposit formation patterns on membrane surfaces

## Membrane Fouling Mechanisms

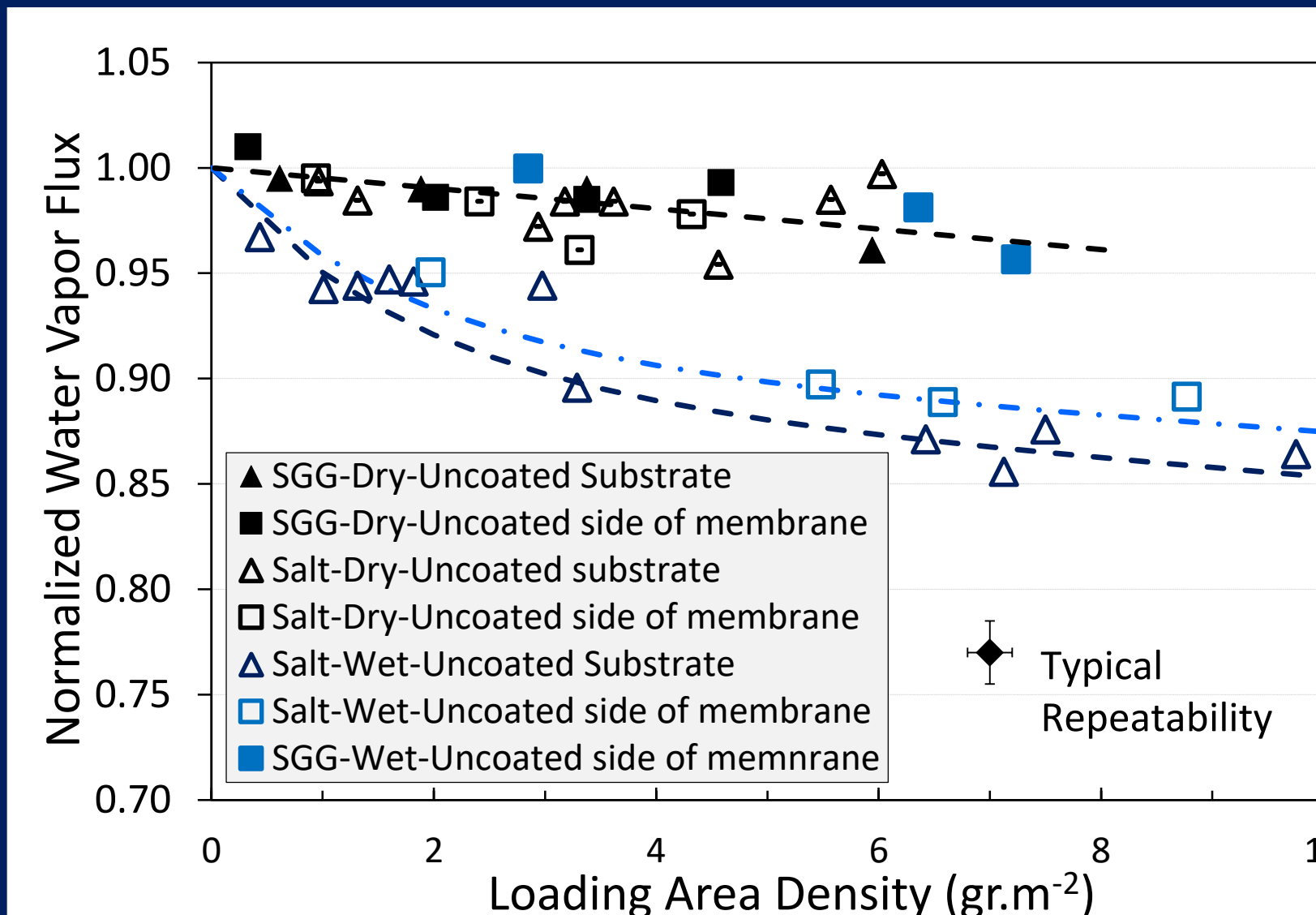


Figure 7: Changes in membrane flux resulted from particle loading

- SEM images, as well as the fact that the loaded membrane flux can be restored to its pre-exposure value by a simple wash, imply that re-crystallization of salt ions dissolved in condensed water onto the pores of membrane substrate is a potential explanation for the changes.

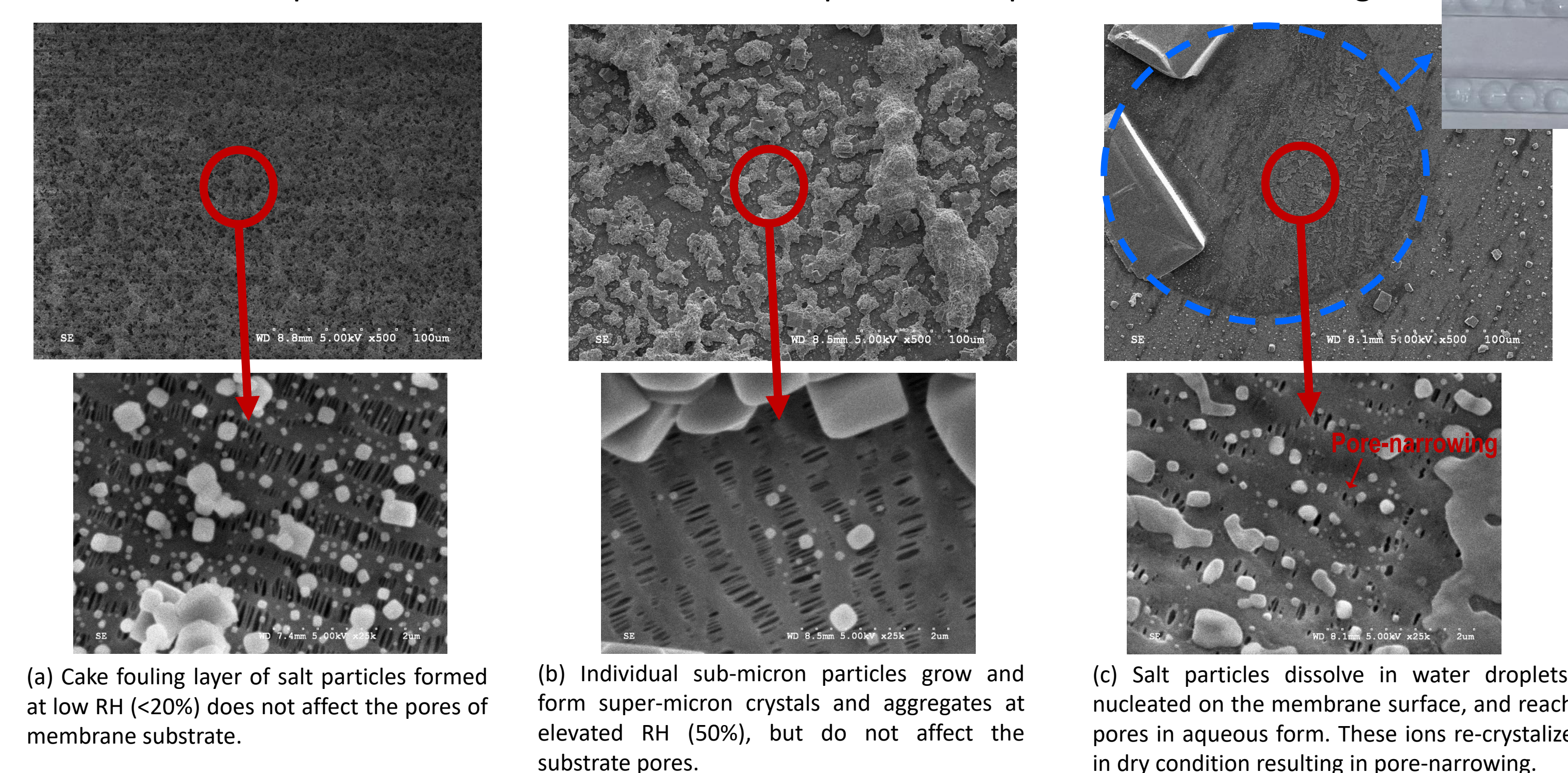


Figure 8: Structural Changes of hygroscopic salt particles deposited at different RH.

- Membranes wet-loaded with hygroscopic particles on the 'uncoated' side (Fig. 7) showed vapor flux decline up to 15%, whilst membranes loaded on the 'coated' side did not show a significant flux decline under similar wet loading conditions.
- Uncoated substrate samples show a consistently higher flux decline compared to membranes under similar wet loading. This supports the hypothesis that observed flux decline is caused by increased resistance of the microporous membrane substrate due to a pore-narrowing process.

## Conclusions

- Moderate membrane fouling by both hygroscopic and non hygroscopic particles in dry conditions (i.e. no condensation occurs) has minimal impact on water vapor flux of membrane samples.
- Heavy loadings of such particles on both 'coated' and 'uncoated' sides that form a thick cake layer (≥membrane thickness) can result in a slight flux decline (<5%) due to the added resistance of the cake layer.
- Deposition of hygroscopic nanoparticles on the 'uncoated' side of microporous substrate of membrane, in the presence of condensation, could significantly decrease water vapor transport through membrane samples (up to 15%).
- Air-side particulate fouling of composite membranes can be controlled and minimized by measures such as: (1) Exposing coated side of membrane to the stream with more nanoparticles; (2) Membrane module installations such that any potential condensation occurs on the coated side; (3) Periodic membrane cleaning (e.g. washing with distilled water)

## References

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