Global Air Pollutant Database and Real-Life Filter Test Rig in Laboratory

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Air Filters Are Usually Not Customized by Operating Conditions

PHOTO CREDIT: ENVIRONMENT CALIFORNIA

Differences in Operating Conditions

- **Particulate air pollutant**
  - –Particle composition (St. Louis vs. Seattle)
  - –Size distribution (Phoenix vs. Los Angeles)
  - –Concentration (Beijing vs. Haikou)
- **Meteorological condition**
  - –Temperature (Minneapolis vs. Orlando)
  - –Relative humidity (Urumqi vs. Taipei)

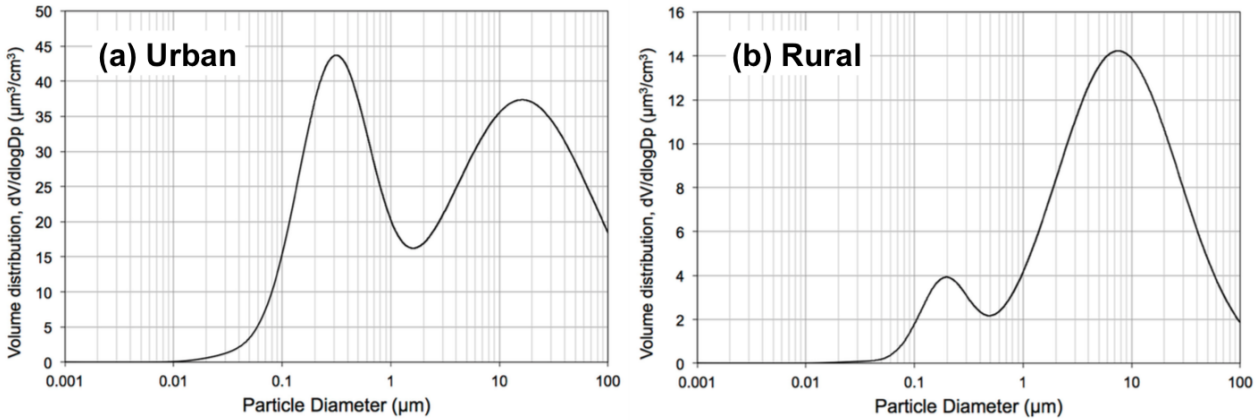
Complexity in operating conditions may cause unexpected filter failure.

Filter Testing Standards

Standard	Test Particles	Relative Humidity	Temperature
ASHRAE 52.2:2007	KCl / Synthetic Loading Dust	20% - 65%	10-38℃
ISO 5011:2014	ISO A2 & A4 dust	55±15%	23±5℃
EN 779:2012	Synthetic Loading Dust	<75%	-
ISO 16890:2016	Synthetic Loading Dust	45±10%	23±5℃

Mostly dust

Wide, uncontrolled



Seinfeld and Pandis (2006) and Jaenicke (1993)

Standards may not represent the real operating conditions.

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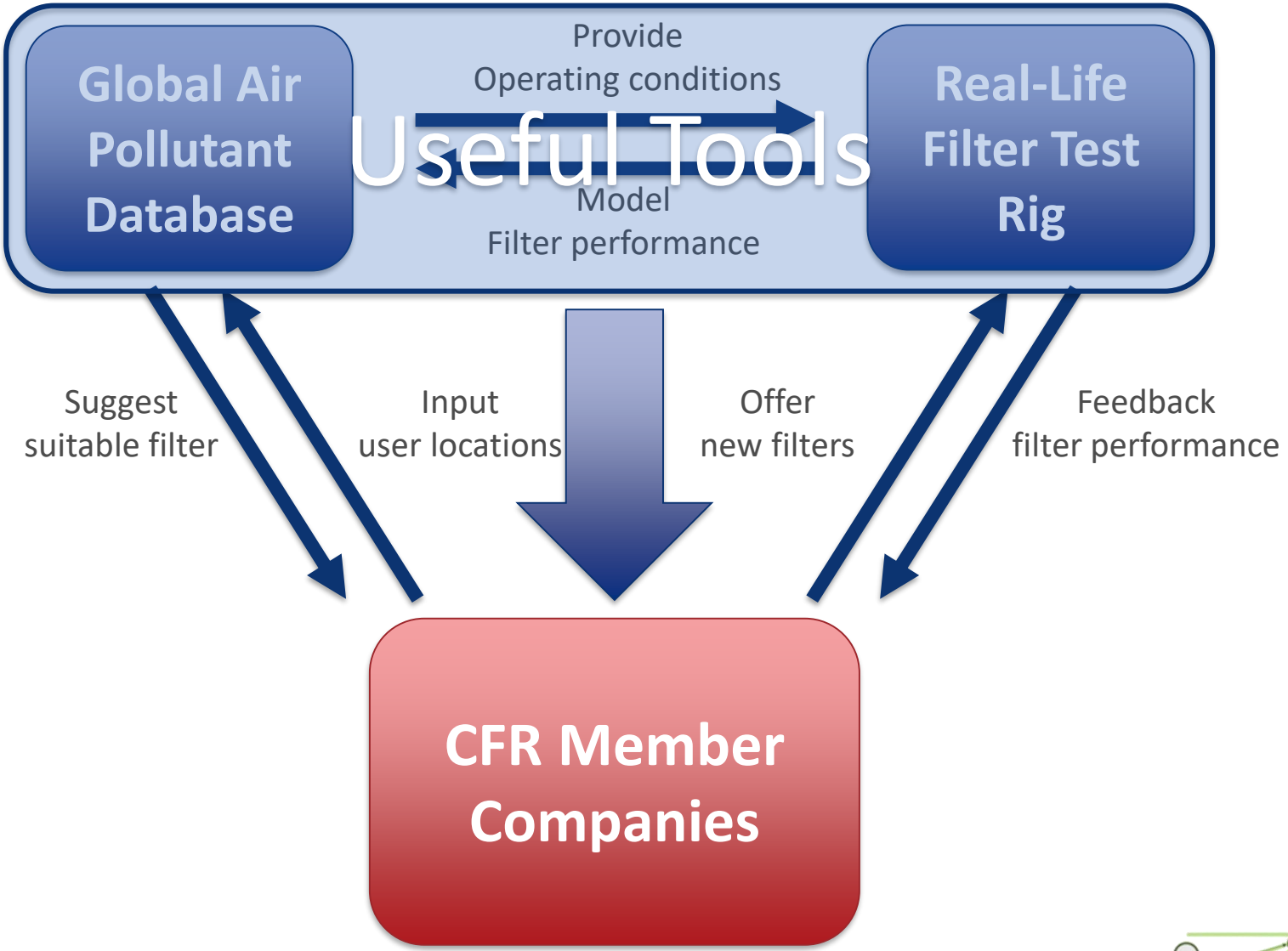
Solutions to Customize Air Filters

- Collect particulate air pollutant and meteorological information of different locations.

Global Air Pollutant Database

- Perform systematic and thorough research on filter loading performance by various factors, including filter type, particle, RH and temperature.

Real-Life Filter Test Rig


Global Air Pollutant Database
Provide
Operating conditions
Useful Tools
Model
Filter performance
Real-Life Filter Test Rig
Suggest suitable filter
Input user locations
Offer new filters
Feedback filter performance
CFR Member Companies

Global Air Pollutant Database

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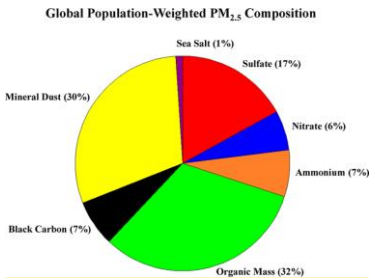
Existing Air Pollution Database

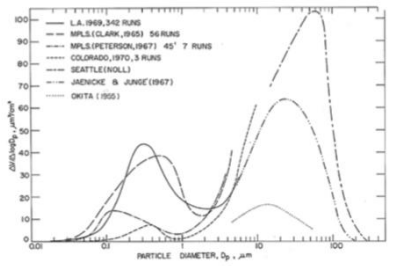
- **Some big international organizations(WHO, World Bank) and air pollution protection agencies(EPA, MEP of China) have air pollution database.**
  - –Strengths
    - Wide coverage
  - –Weaknesses
    - Old data
    - Annual data, not monthly or seasonally
    - No meteorological data

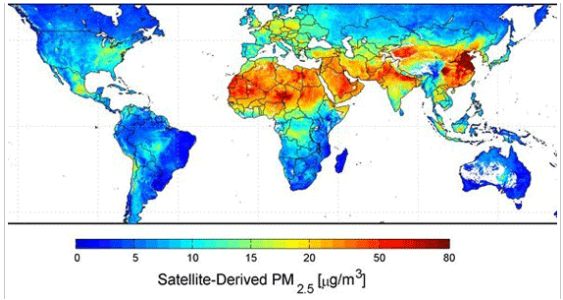
Existing databases cannot offer sufficient information to us

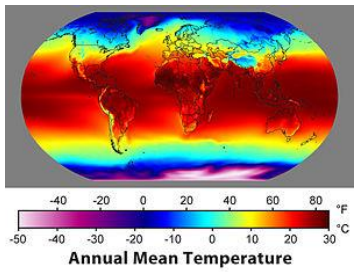
Global Air Pollutant Database: Data Categories

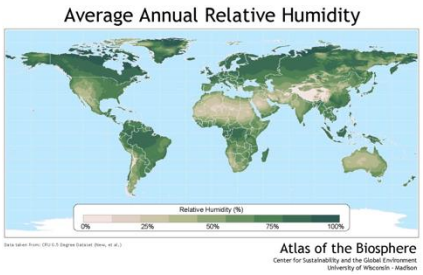
- **Air pollutant**
  - $PM_{2.5}$, PM_{10}
    - Speciation
    - Size distribution
    - Concentration
- **Meteorology**
  - Temperature
  - Relative humidity











Philip et al., 2014;Whitby et al. 1972
Dalhousie University, Aaron van Donkelaar
New et al. 2002, Reynolds et al. 2002, Kalnay et al. 1996
Climate Research Unit, Univ. of East Anglia.

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9 US Cities Represent Each Climate Region

•Thomas R. Karl and Walter James Koss, 1984: *"Regional and National Monthly, Seasonal, and Annual Temperature Weighted by Area, 1895-1983."* Historical Climatology Series 4-3, National Climatic Data Center, Asheville, NC, 38 pp.

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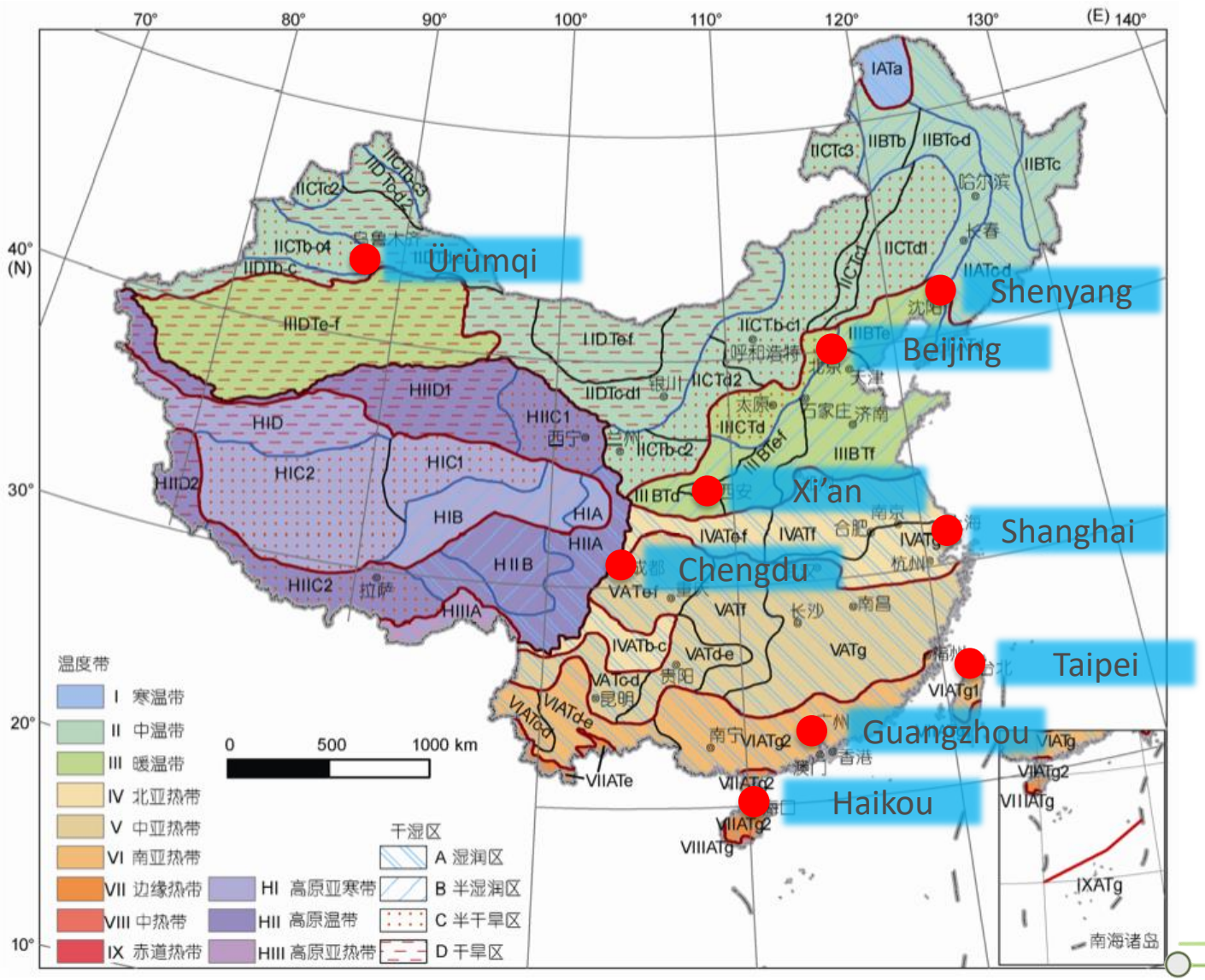
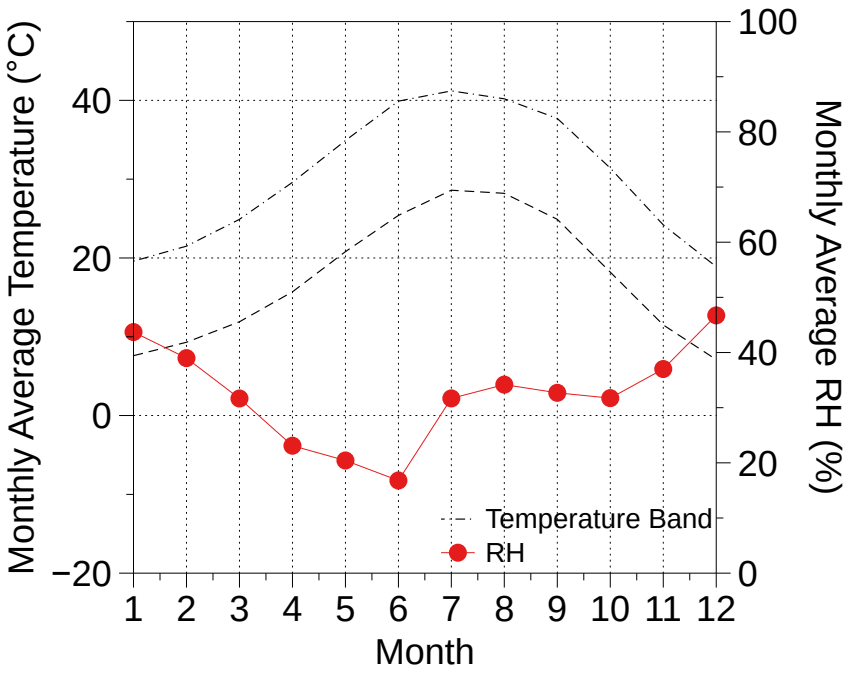
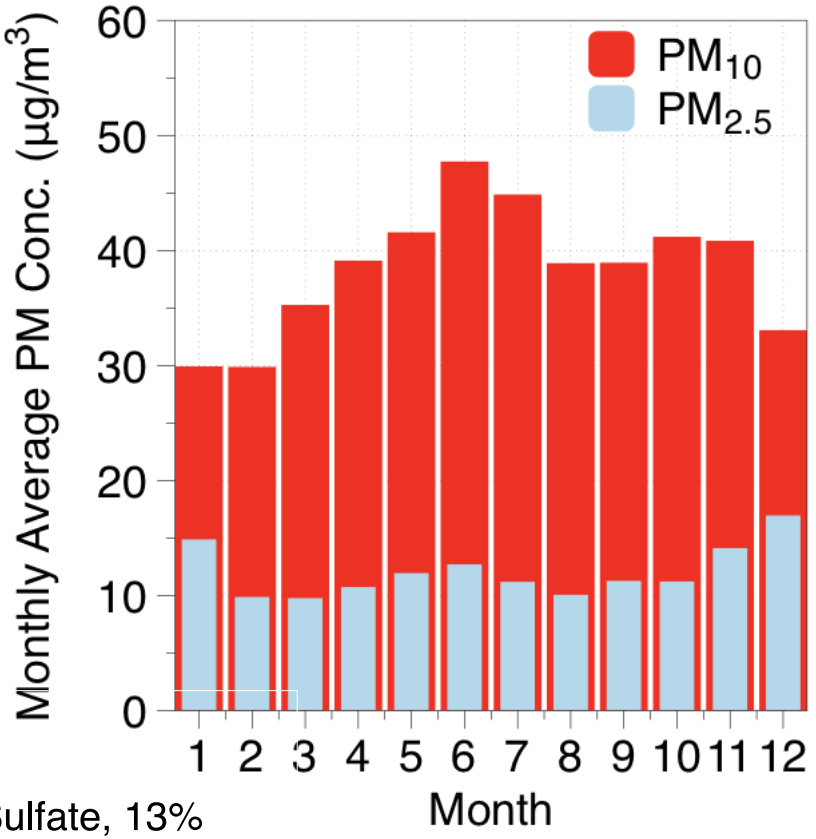
9 Chinese Cities Represents Climate Regions

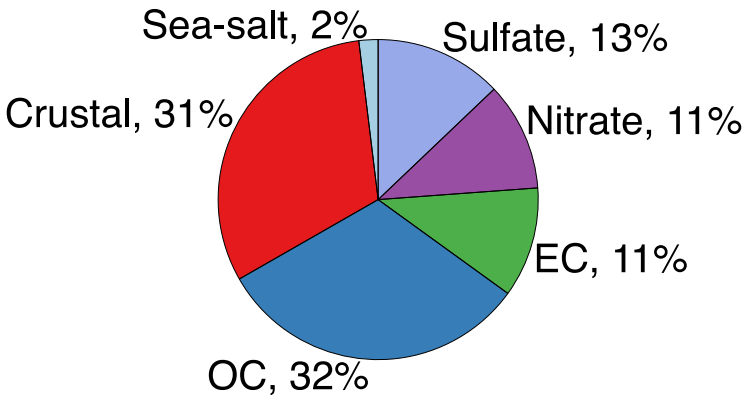


ZHENG et al. 2013

Phoenix

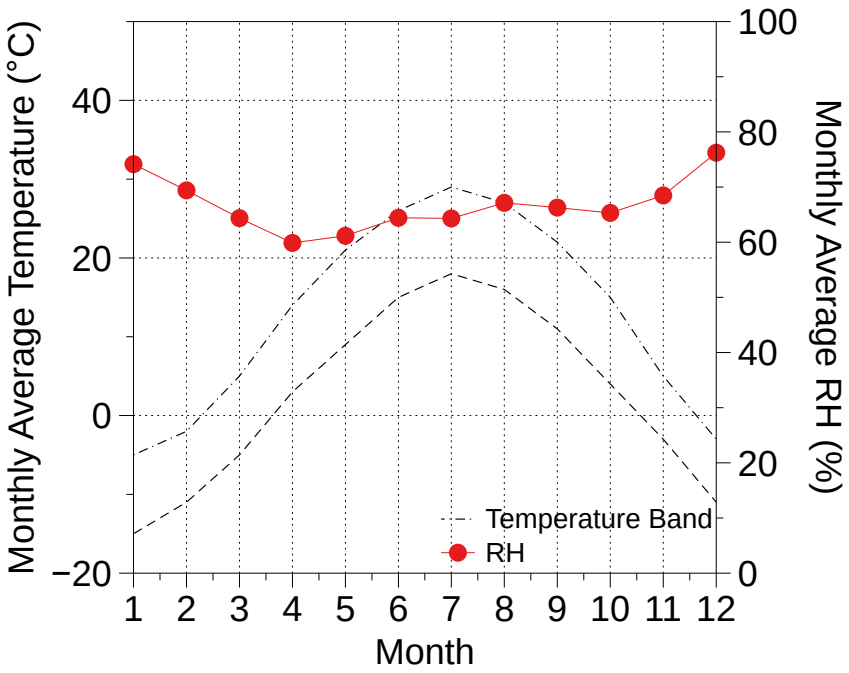


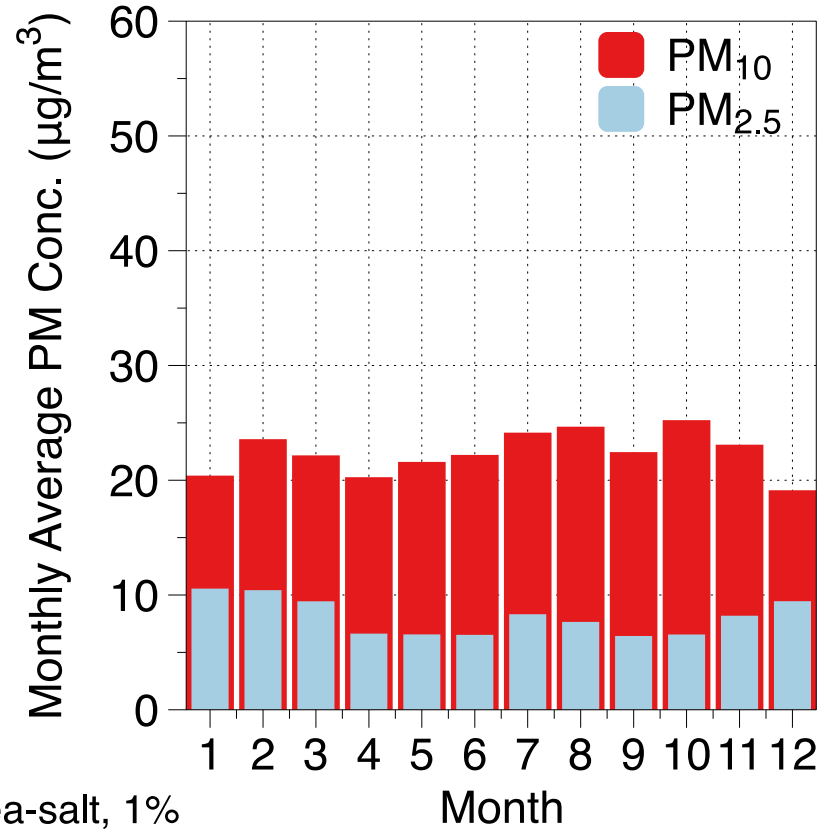


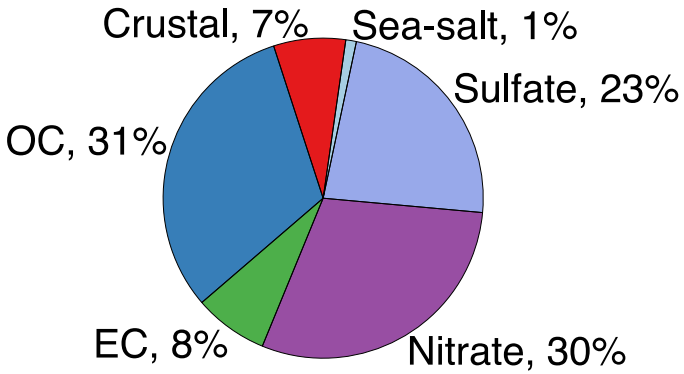


EPA, NOAA, wunderground.com

Minneapolis

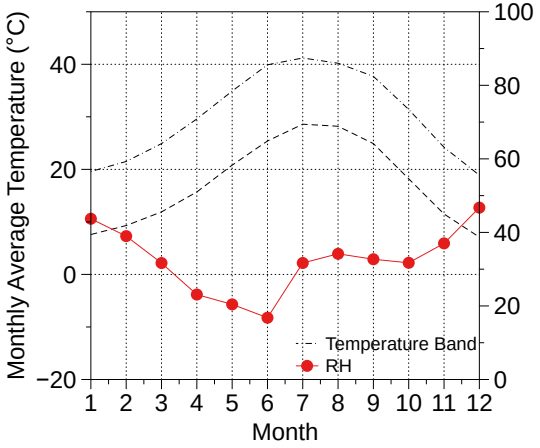


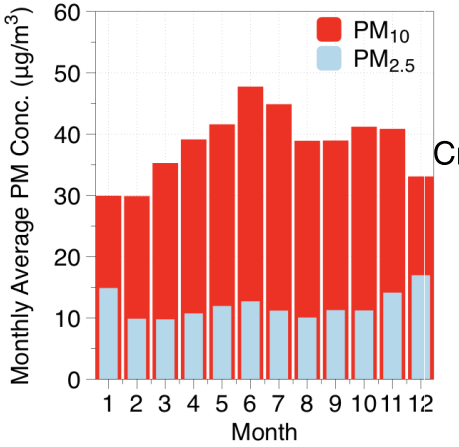


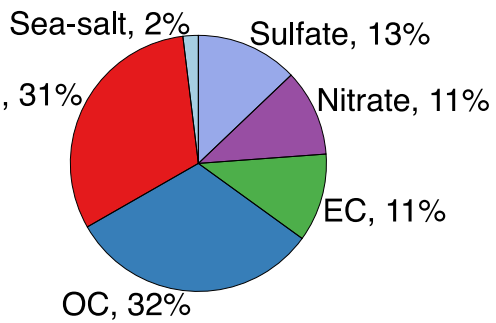


EPA, NOAA, wunderground.com

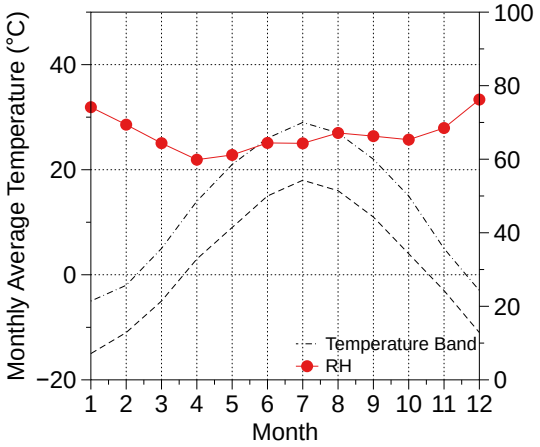
Phoenix

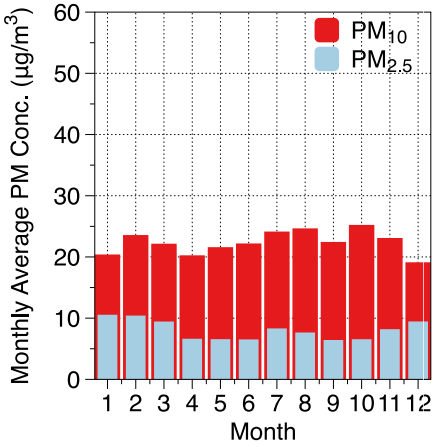


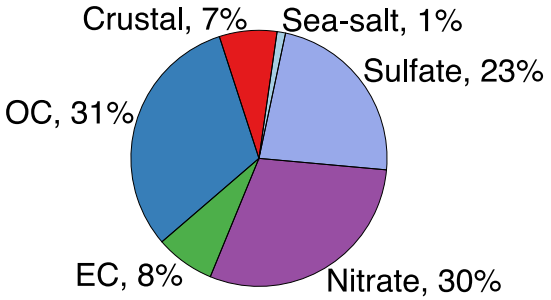




Minneapolis







EPA, NOAA, wunderground.com

UNIVERSITY OF MINNESOTA

Twin Cities • Duluth • Morris • Crookston • Rochester • Other Locations

CFR | Filter Analysis | Dust Loading | Pleating Design

General Parameters

Gas viscosity 0.000181 g/cm*s

Face velocity 10 cm/s

Atmospheric pressure 101325 Pa

Temperature 293.15 K

Dust cake porosity 0.8464

Estimate cake porosity ☑ What is this?

Void Function Vanni-Happel

Location ✓

Season: Summer

Filter type: Nano-fiber coated cellulose filter

----------US----------
Houston
Los Angeles
Minneapolis
New York
Orlando
Phoenix
Rapid City
Seattle
St. Louis
---------China---------
Beijing
Chengdu
Guangzhou
Haikou
Shanghai
Taipei
Urumqi
Xi'an

Aerosol 2

0 % of number c

Geometric mean of v

Geometric standard

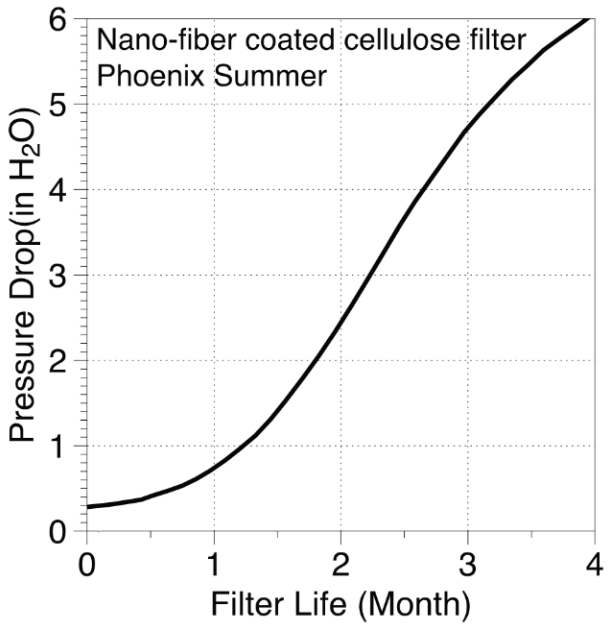
Particle density 1

Dynamic shape facto

Loading Curve

Show Pr

t diameter 1 µm



Previous Version

Start Monitor - Stop Monitor - Clear Monitor - Era

Real-Life Filter Test Rig

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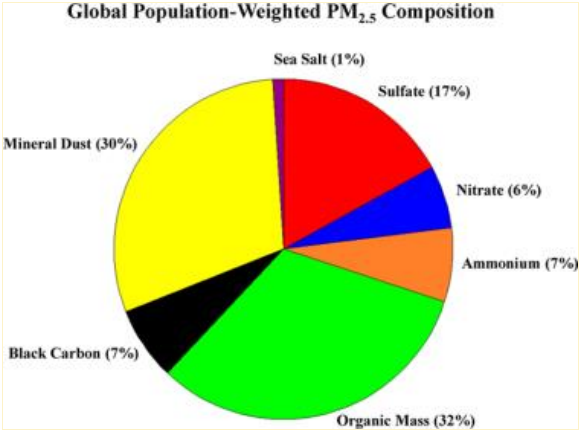
Current Commercial Filter Test Rig

+ In accordance with specific filter test standards
+ Wide particle size measuring range
+ Available in market
- Large area filter is needed to perform a single test
- No capability to measure fine particles
- Cannot test multiple particle species simultaneously

Existing test rig cannot fit the need of the laboratory research.

Real-Life Filter Test Rig

- **Generate atmospheric-like particles simultaneously**
  - –Dust
  - –Salt
    - NaCl
    - $(NH_4)_2SO_4$
    - NH_4NO_3
  - –Organic matter
  - –Soot

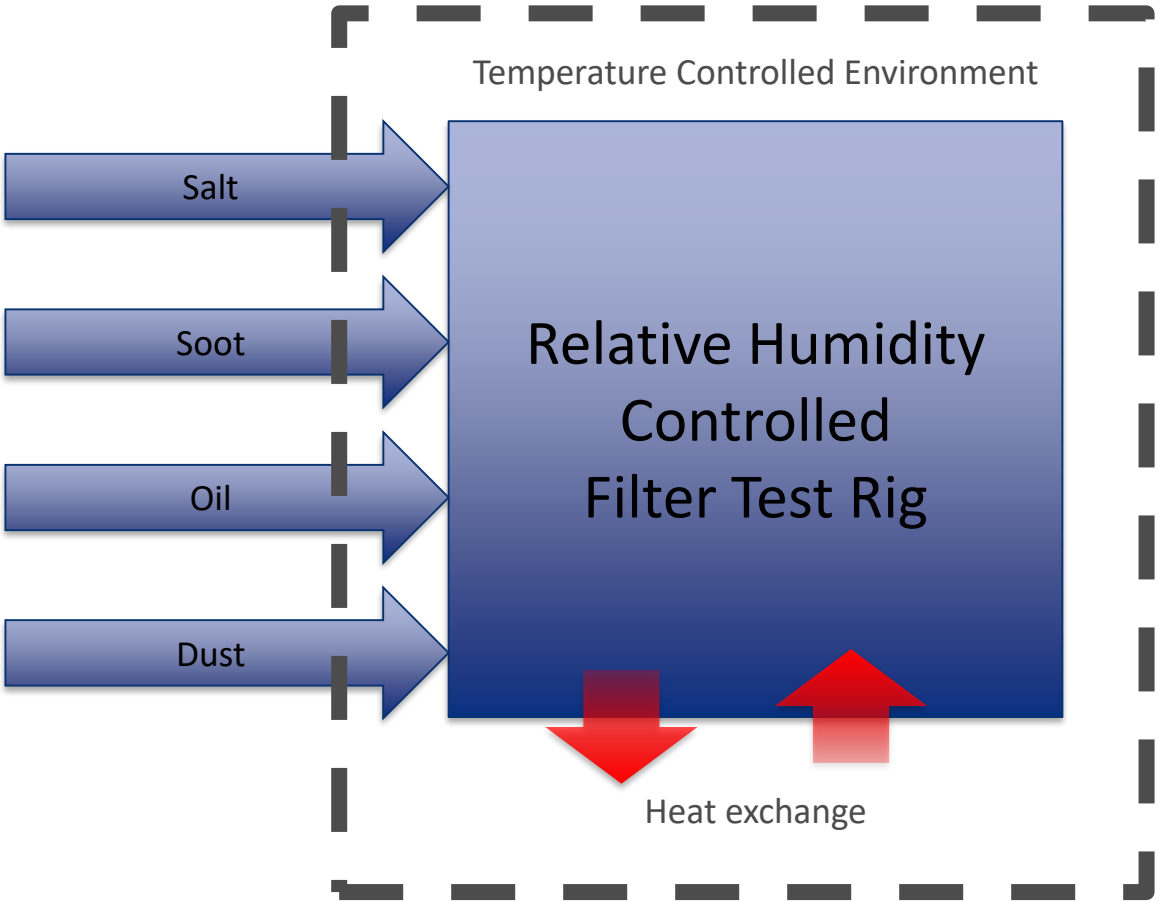


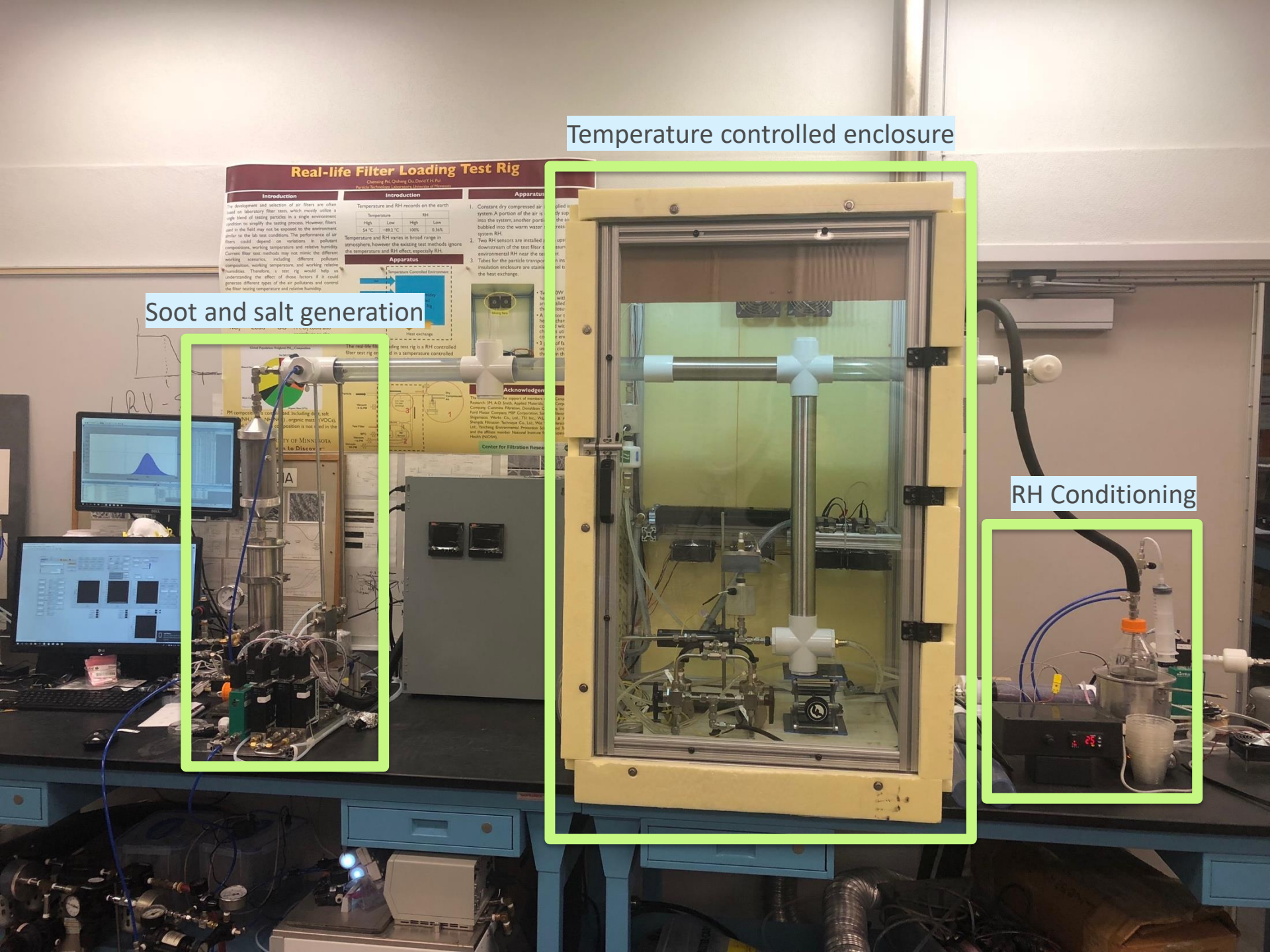
- **Simulate operating environments (Temperature, RH)**
- **Two filter samples (Φ47mm) could be tested at the same time to accelerate the testing process**

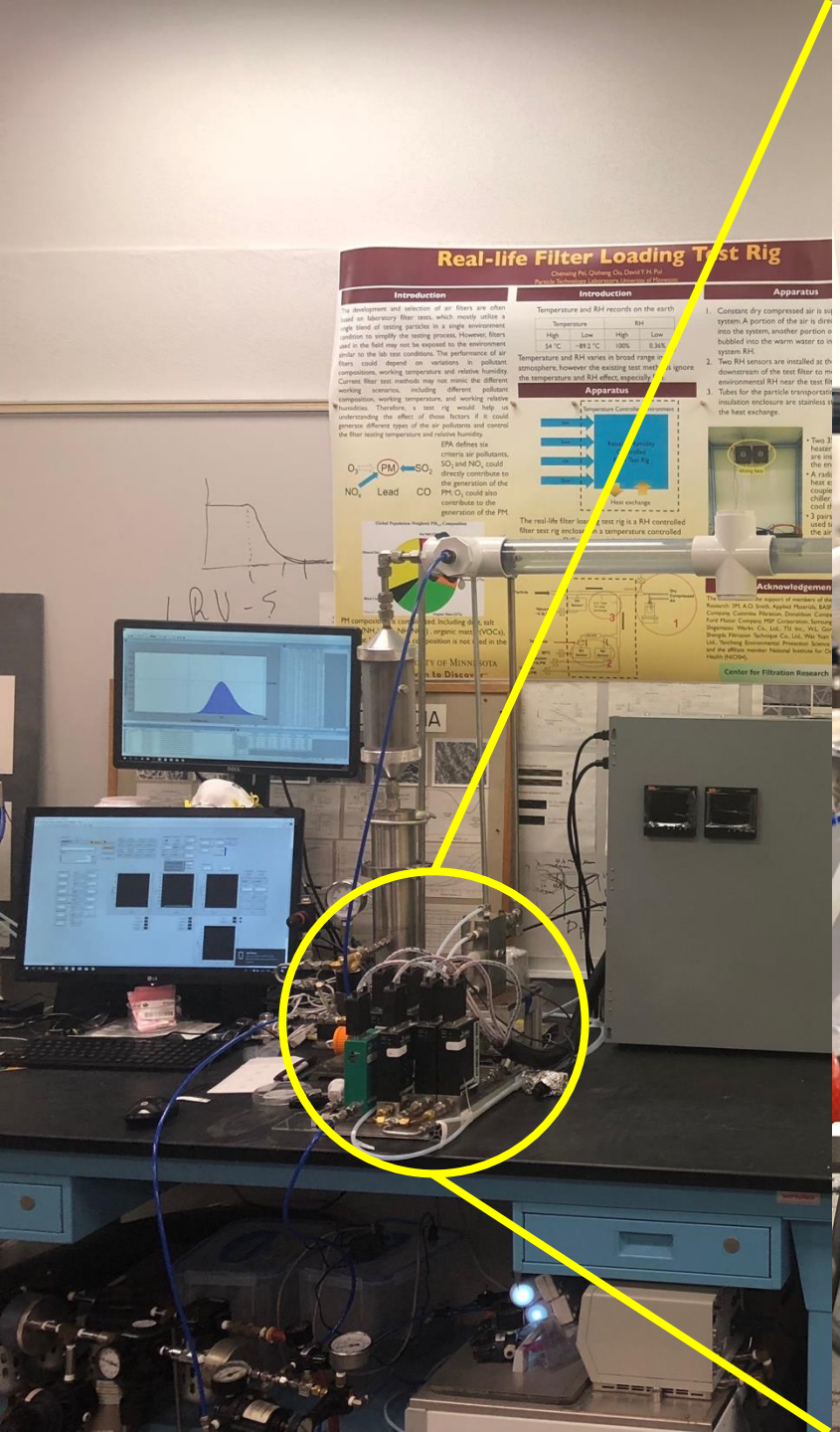
It is suitable to perform the laboratory research.

Philip et al., 2014

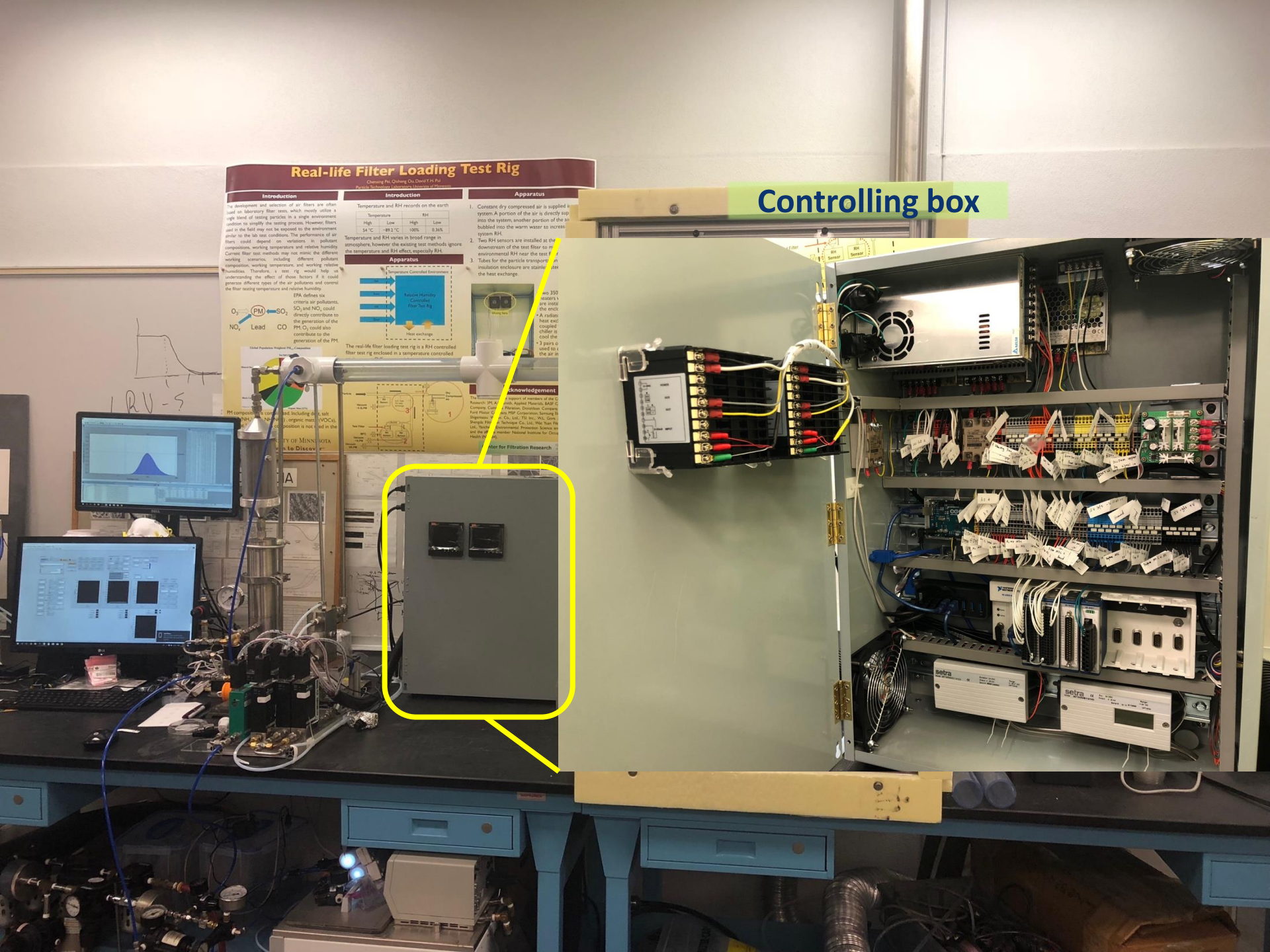
Real-Life Filter Test Rig Schematic

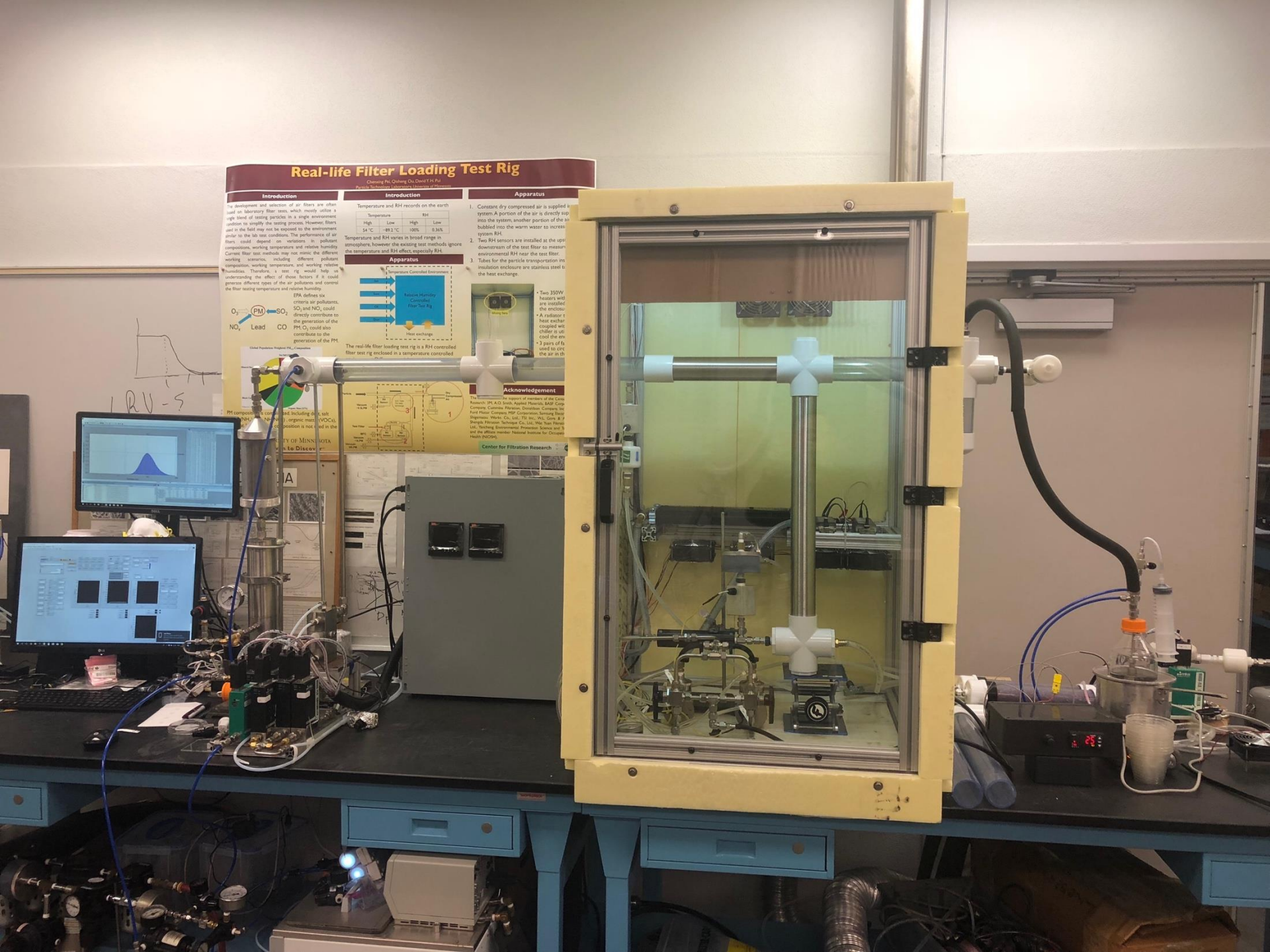



Real-life Filter Loading Test Rig
Introduction
Apparatus
Soot and salt generation
Temperature controlled enclosure
RH Conditioning



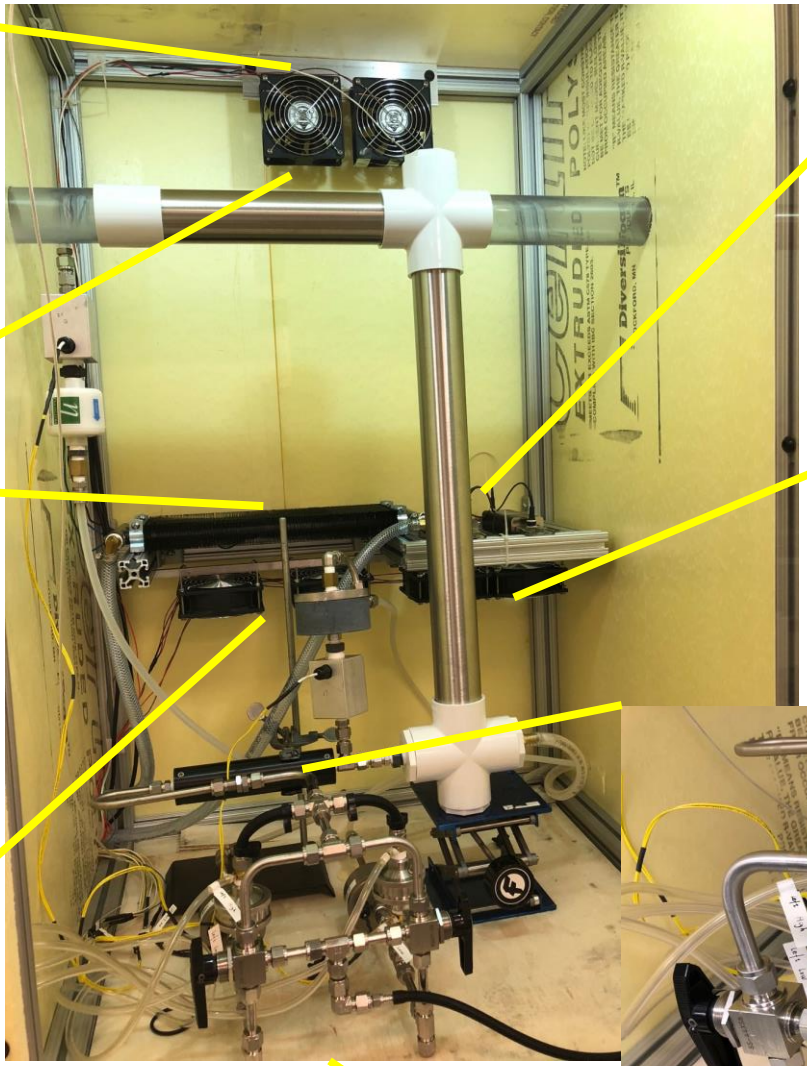
Home-made soot generator


Real-life Filter Loading Test Rig
Introduction
Introduction
Apparatus
Apparatus
Controlling box


Real-life Filter Loading Test Rig
Introduction
Introduction
Apparatus
Apparatus
Acknowledgement
Center for Filtration Research

Details of the filter test rig

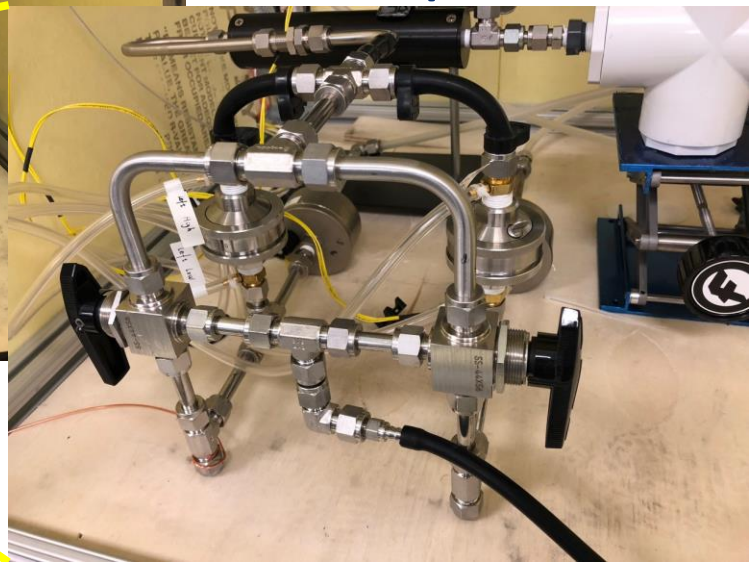
Circulating Fans



Heating Elements& Fans

Cooling Coil & Fans

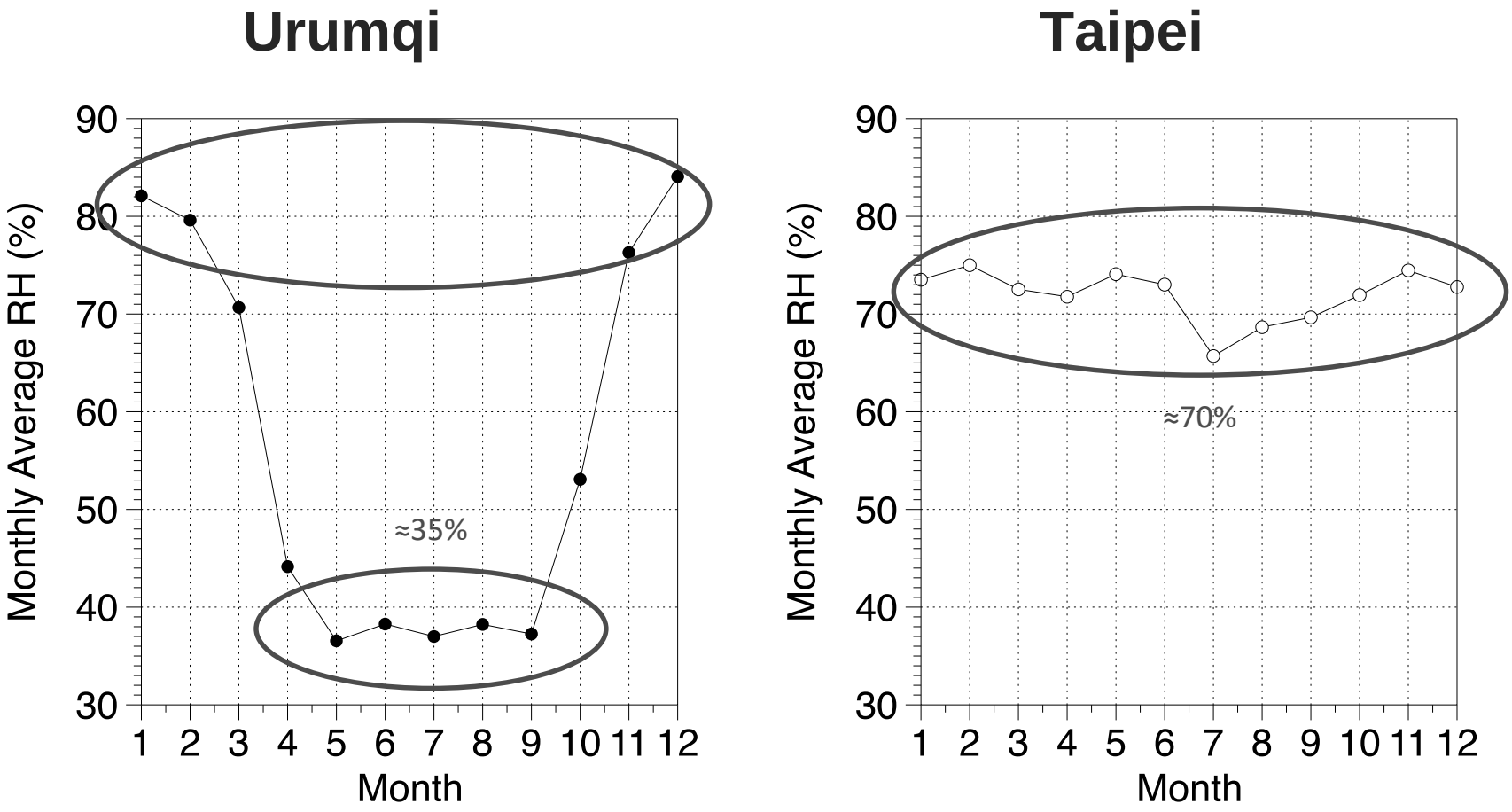
Two-sample holder



Case Study

RH & $PM_{2.5}/PM_{10}$ percentage

Temporal and Spatial Variation of RH

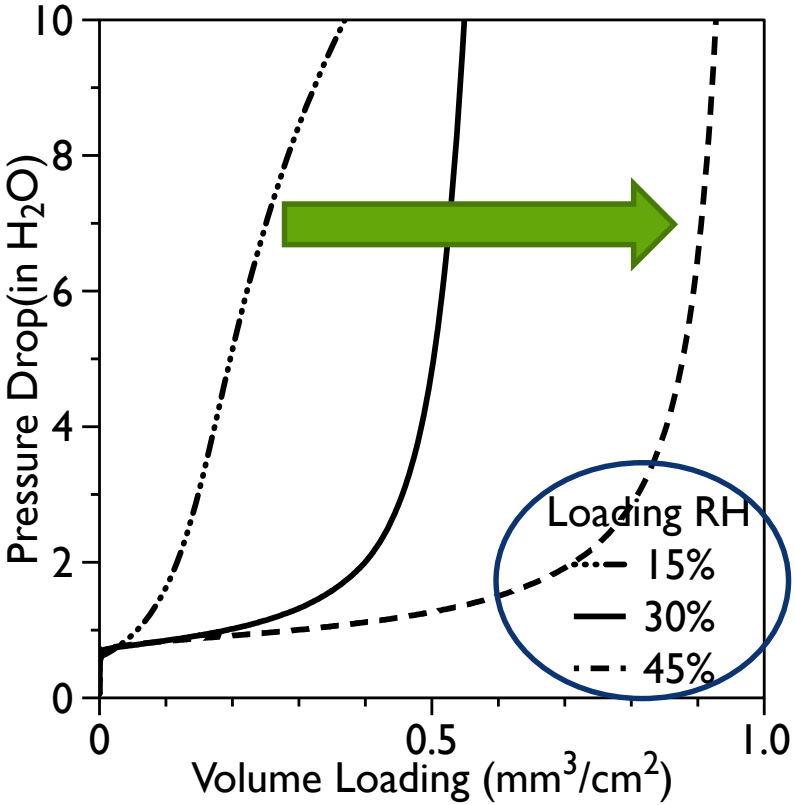


Summer: Urumqi RH≈35% Taipei≈70%

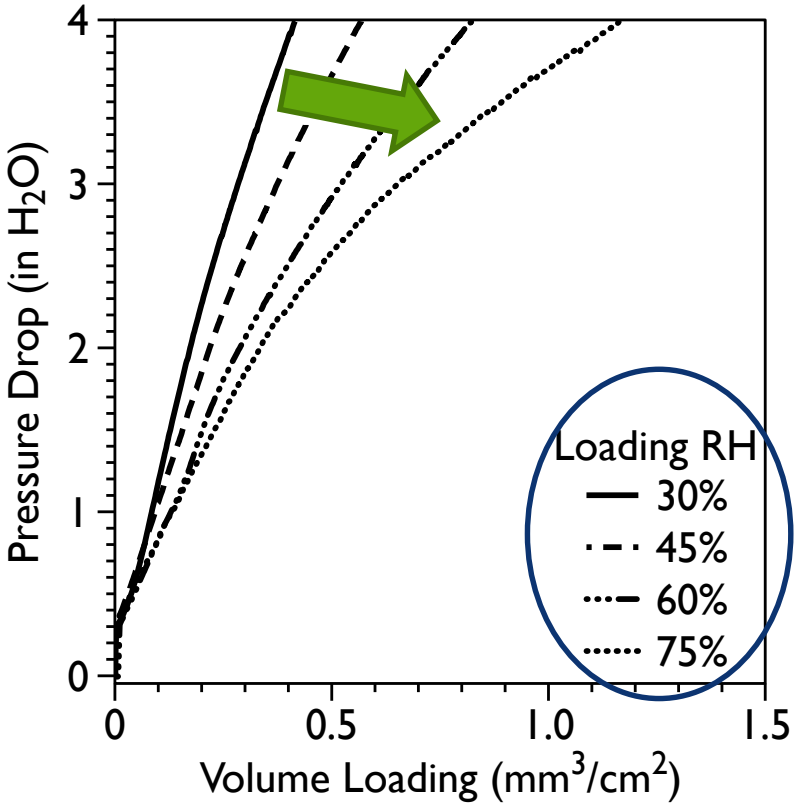
Loading Curves of Various RHs

Summer: Urumqi RH≈35% Taipei≈70%

Cellulose Filter
NH_4NO_3



Nano-fiber Coated Cellulose Filter
$(NH_4)_2SO_4$

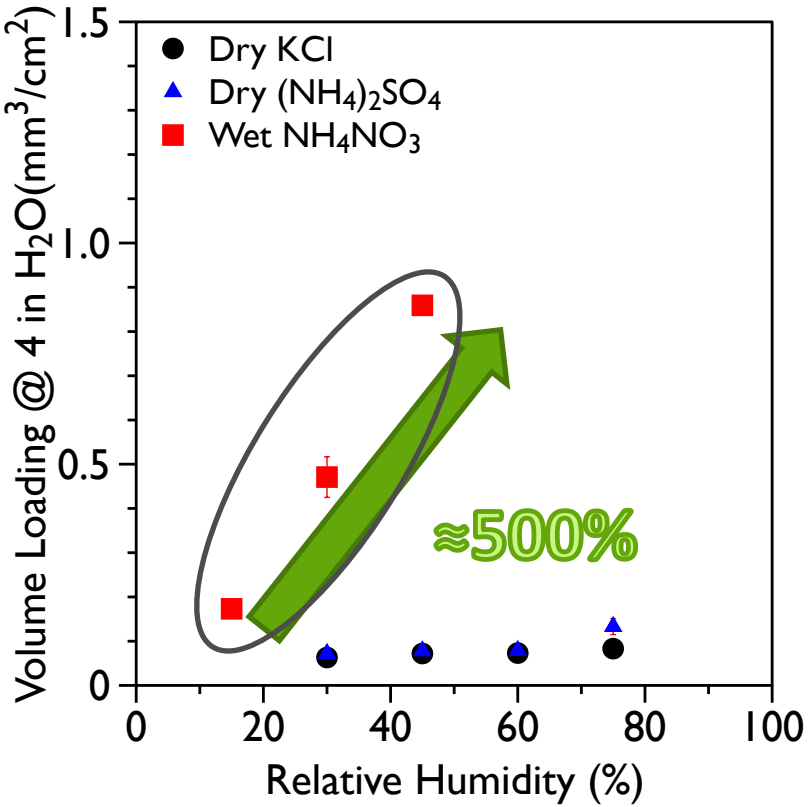


Loading behavior is RH dependent

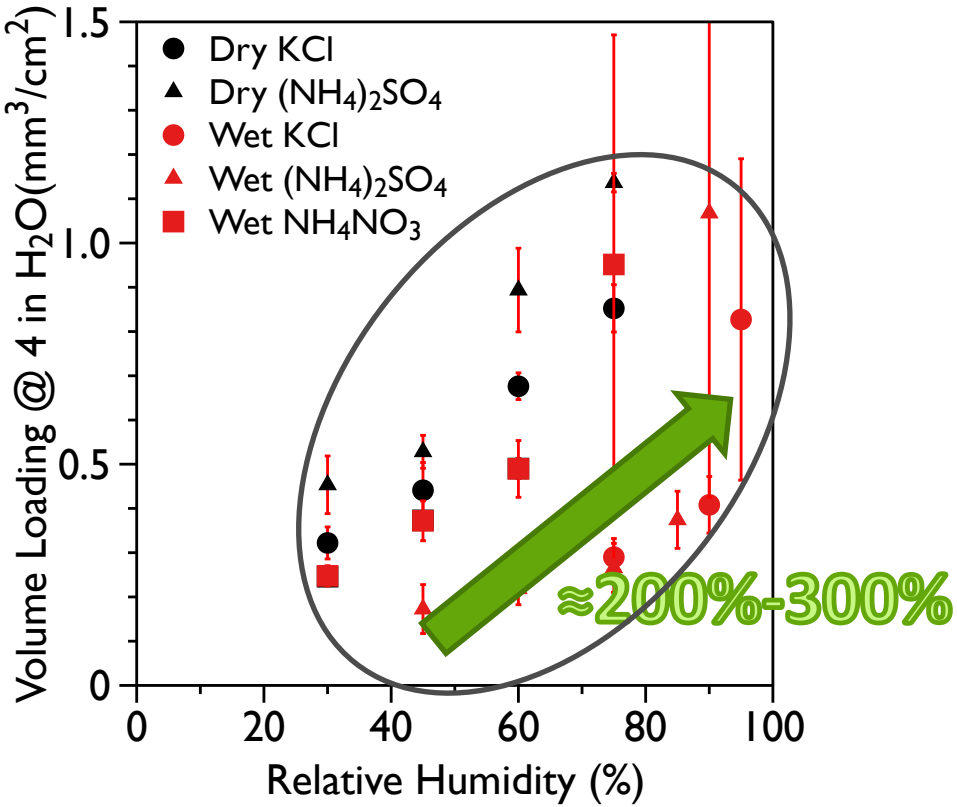
Volume Loading of Two Types Filter Under Different RHs

Summer: Urumqi RH≈35% Taipei≈70%

Cellulose Filter



Nano-fiber Coated Cellulose Filter



Generally, higher loading RH could cause higher holding capacity.

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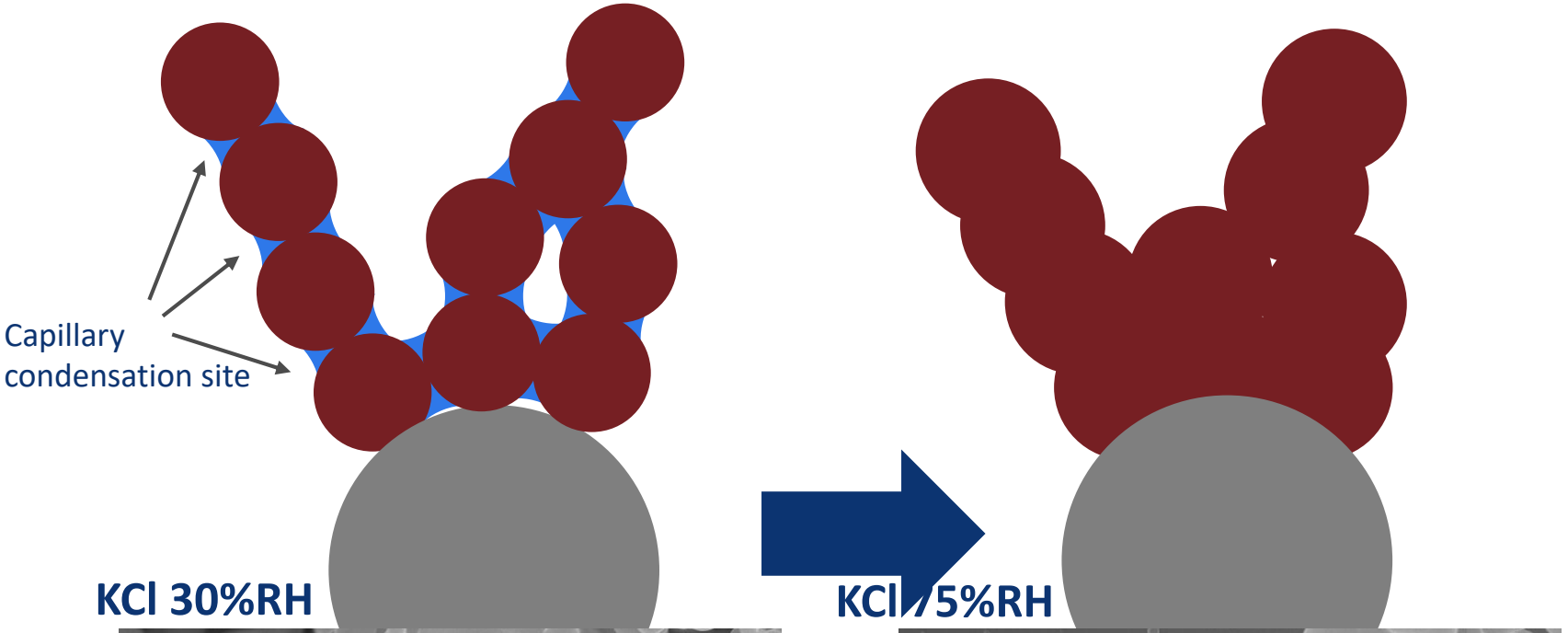
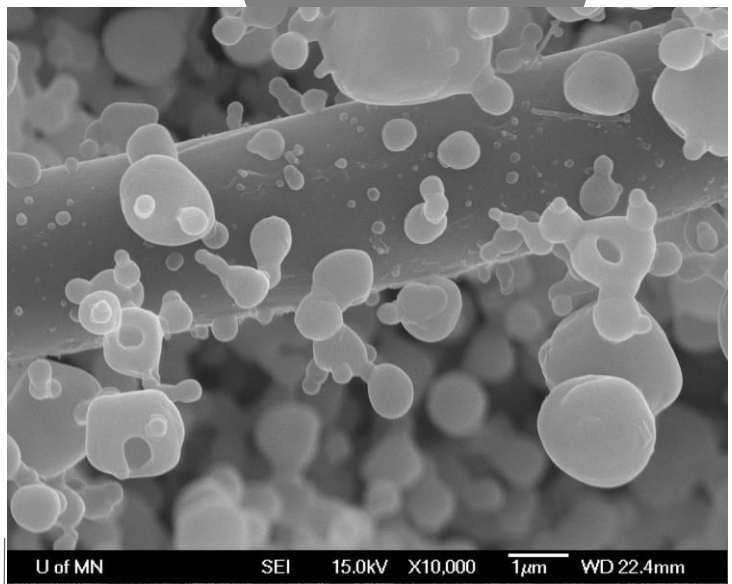
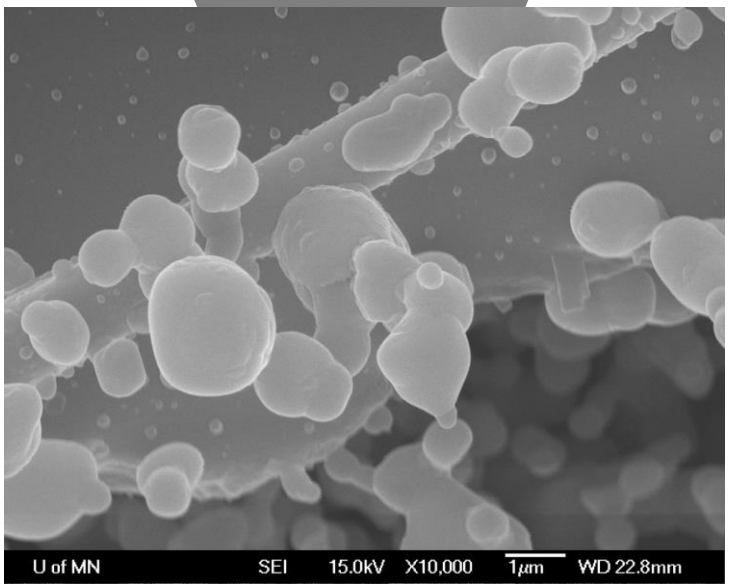
Water could affect the morphology of dendrites







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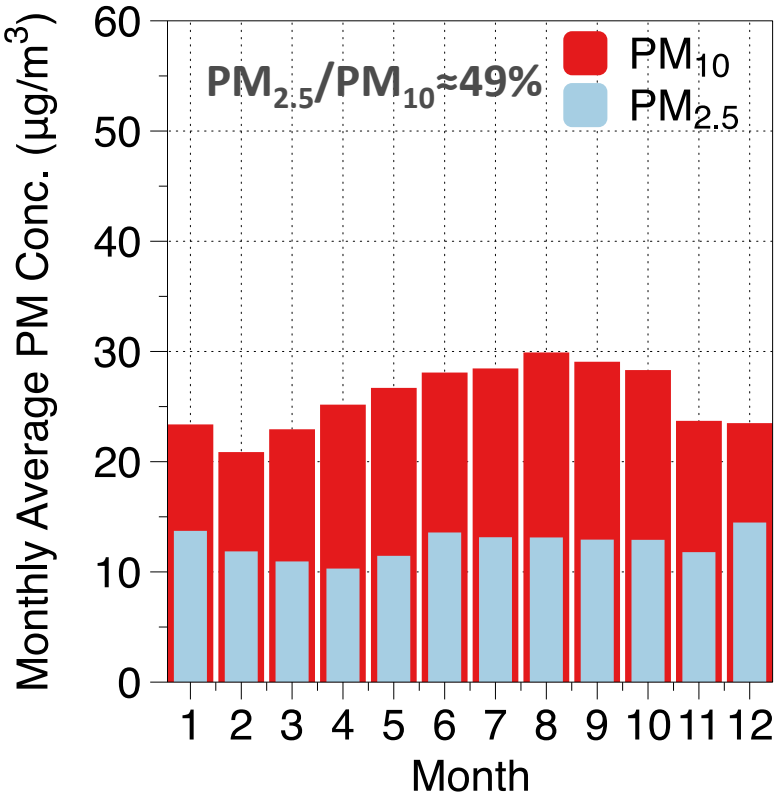
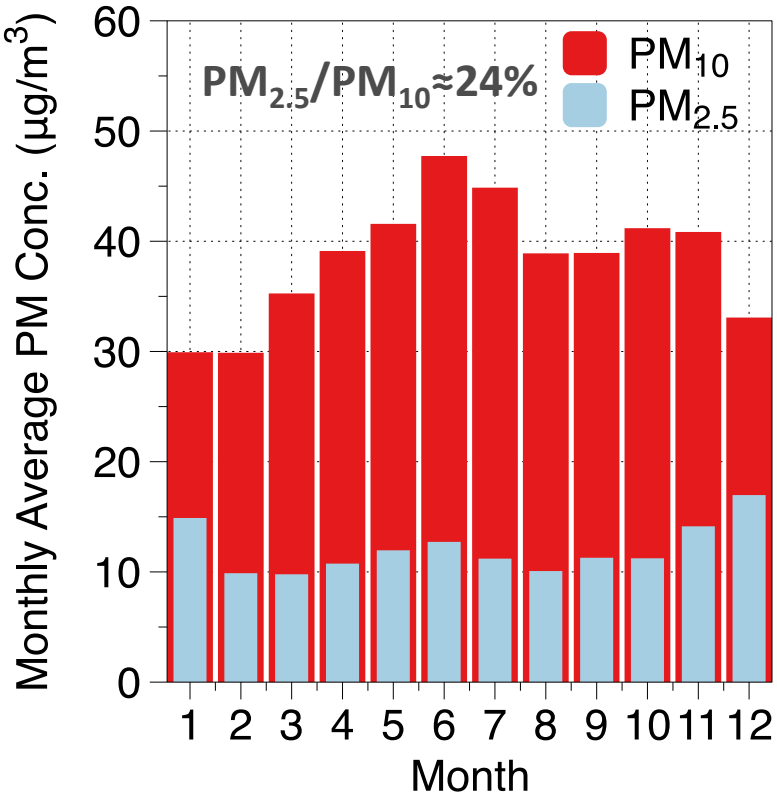
$PM_{2.5}/PM_{10}$ Percentage

Los Angeles



Phoenix



Los Angeles $PM_{2.5}/PM_{10}\approx49\%$

Phoenix $PM_{2.5}/PM_{10}\approx24\%$

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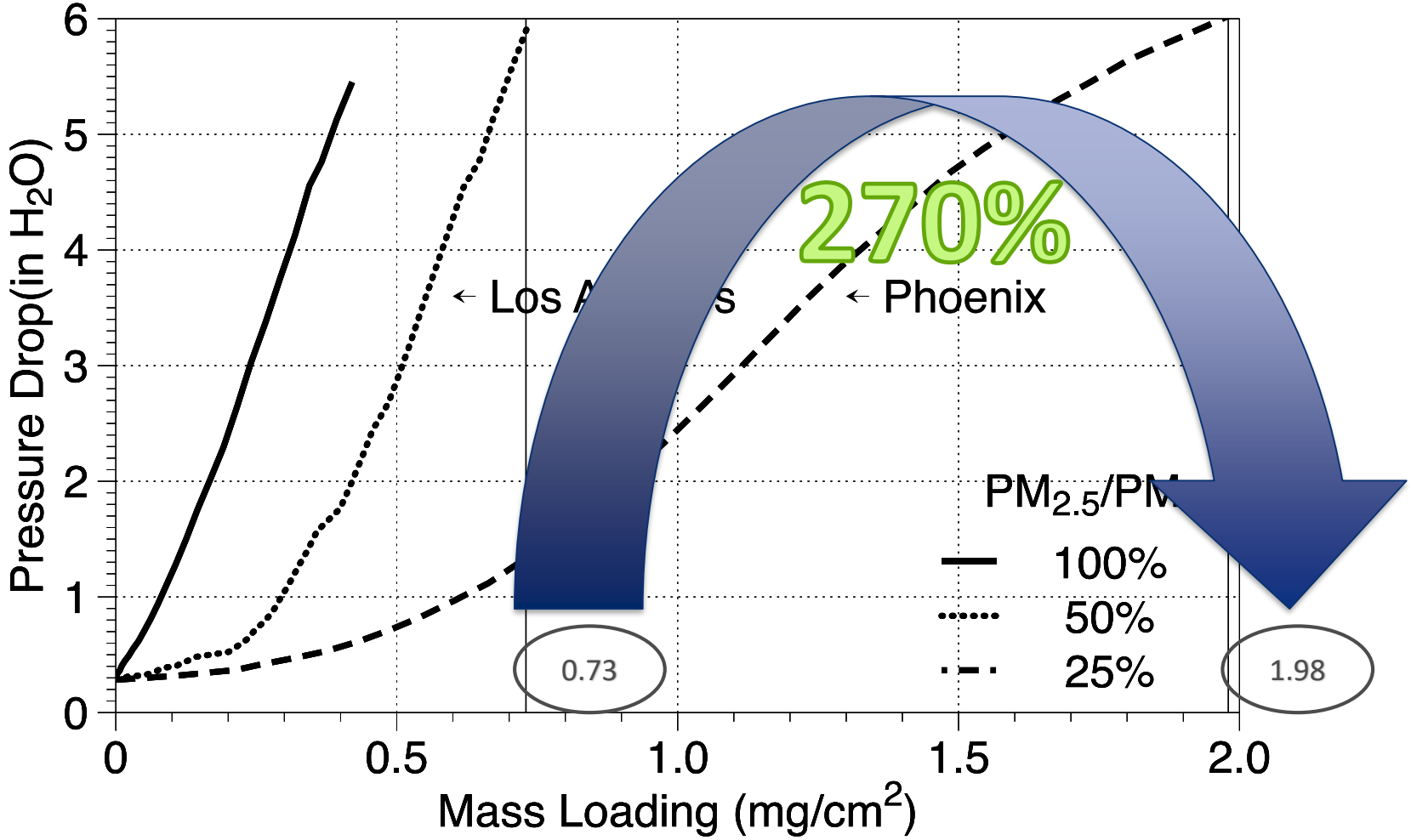
Loading Curves of Different $PM_{2.5}/PM_{10}$ Percentage

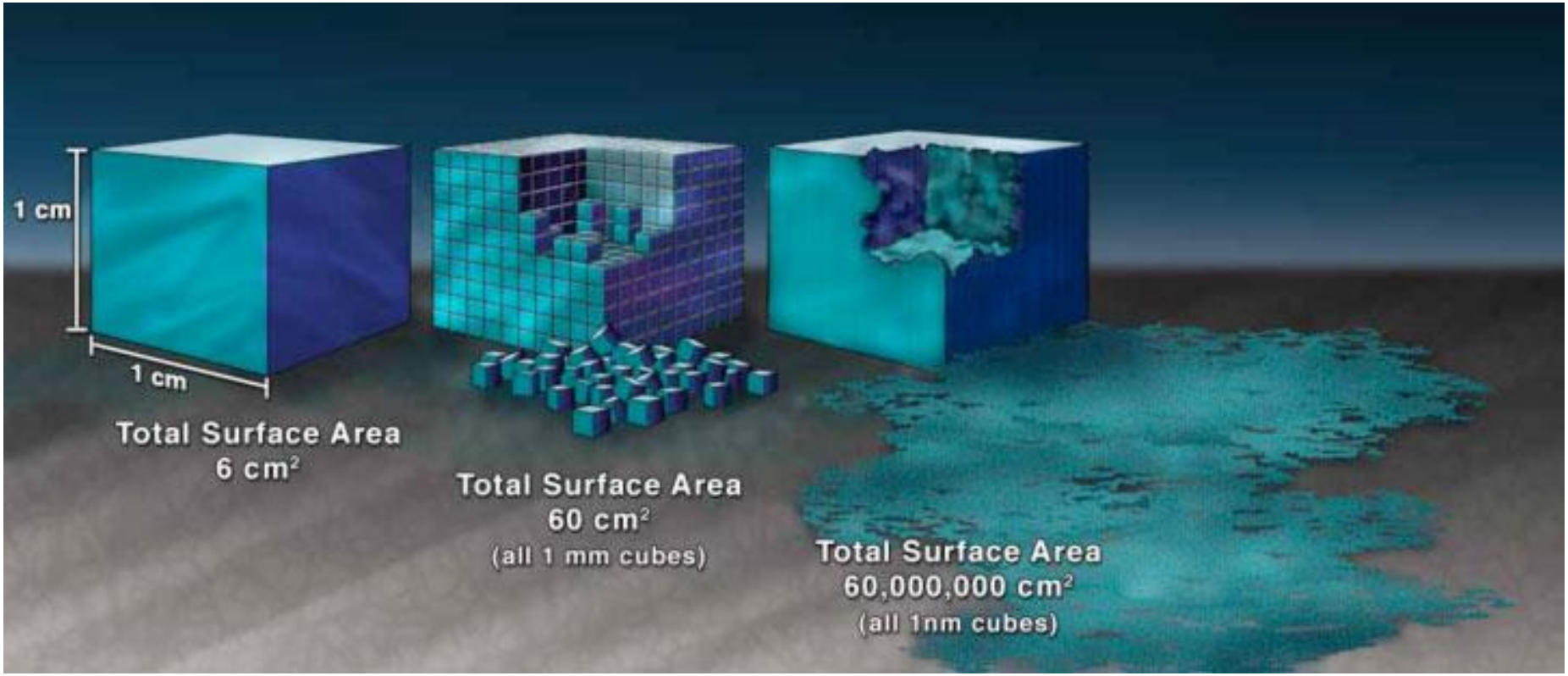
Los Angeles $PM_{2.5}/PM_{10}$≈49% Phoenix $PM_{2.5}/PM_{10}$≈24%



Generally, higher Coarse portion could cause more holding capacity.

Ou & Pui, CFR 2015

Particle size could affect the cake resistance



Smaller particles could cause more resistance by increasing surface area

https://www.nano.gov/nanotech-101/special

Summary

- **Global Air Pollutant Database** is a informative location-based filter selection tool. Air filter manufacture could recommend filters to customer by the product operating location.
- **Real-Life Filter Test Rig** has the capability to control the air filter loading RH and Temperature, meanwhile different kinds of challenge particle could be introduced into the system.
- With the aid of the Real-Life Filter Test Rig, a **systematic and thorough research** of the filter loading under different operating conditions could broaden our understanding on this topic.
- The **combination** of Global Air Pollutant Database and the knowledge mentioned above will be a **useful tool to CFR member companies in filter customization and selection.**