

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



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.**

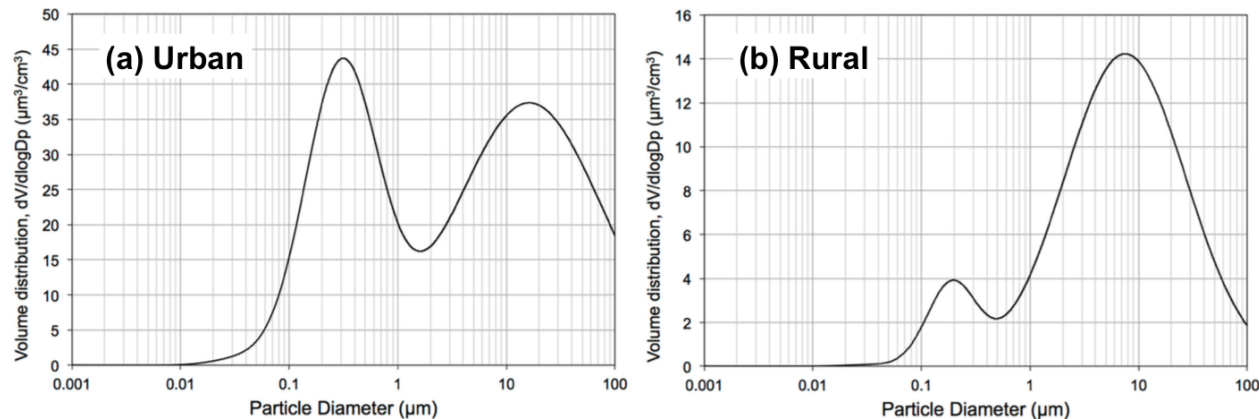


Filter Testing Standards

Standard	Test Particles	Relative Humidity	Temperature
ASHRAE 52.2:2007	KCl / Synthetic Loading Dust	20% - 65%	10-38°C
ISO 5011:2014	ISO A2 & A4 dust	$55 \pm 15\%$	$23 \pm 5^\circ\text{C}$
EN 779:2012	Synthetic Loading Dust	<75%	-
ISO 16890:2016	Synthetic Loading Dust	$45 \pm 10\%$	$23 \pm 5^\circ\text{C}$

Mostly dust

Wide, uncontrolled



Seinfeld and Pandis (2006) and Jaenicke (1993)

Standards may not represent the real operating conditions.



Solutions to Customize Air Filters

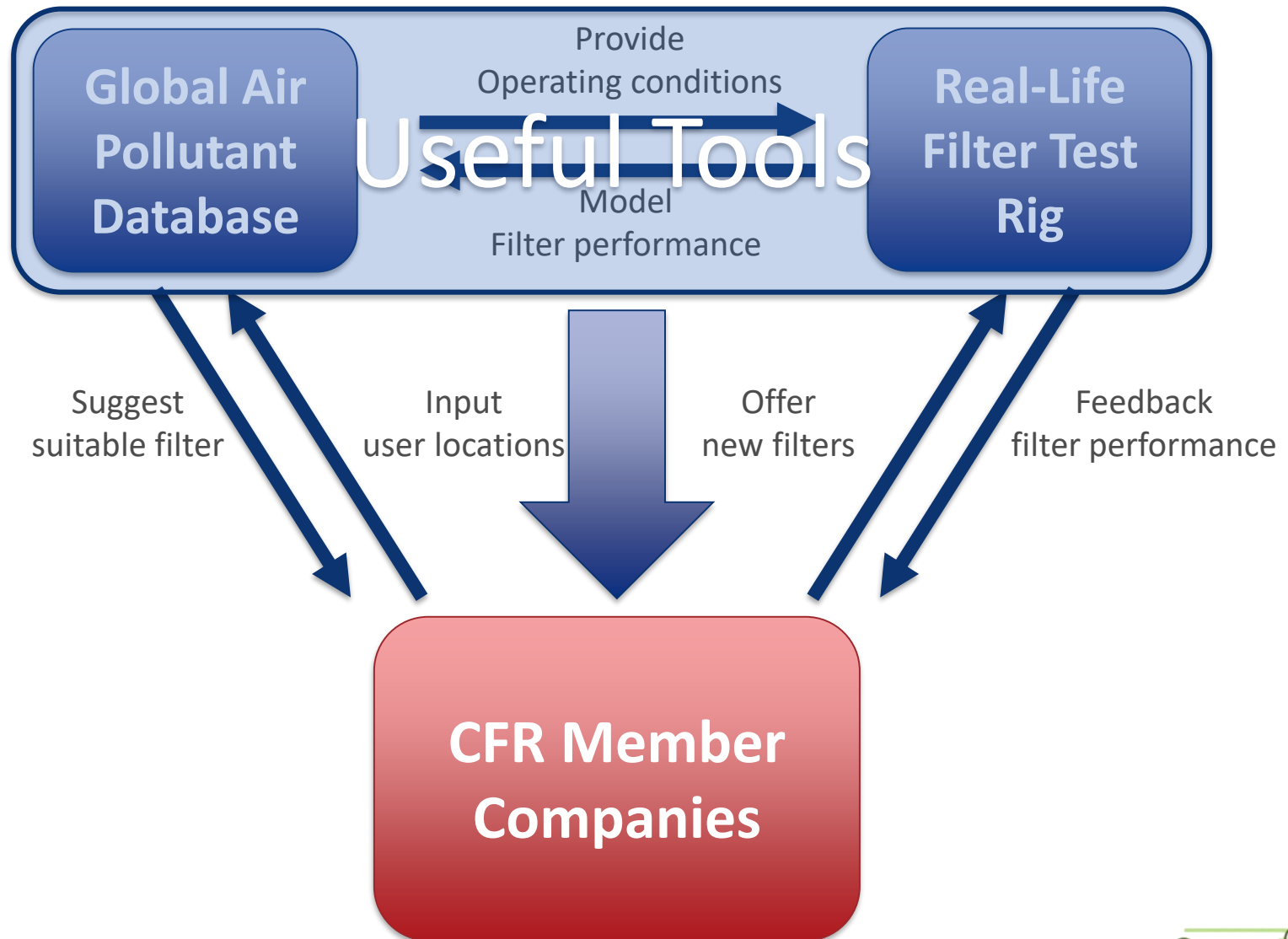
- Collect **particulate air pollutant** and meteorological information of different locations

Global Air Pollutant Database

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

Real-Life Filter Test Rig





Global Air Pollutant Database



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**

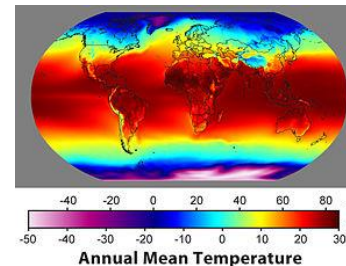
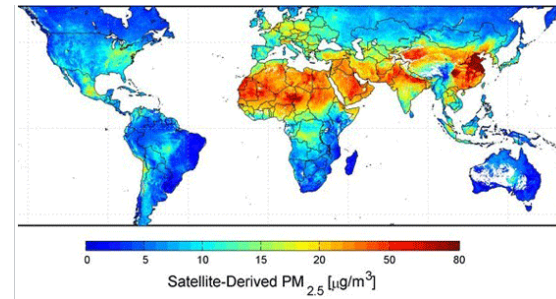
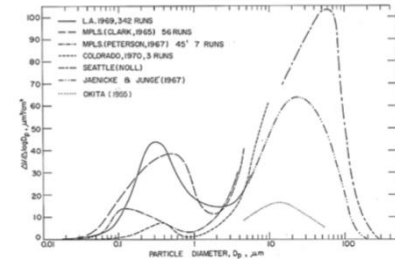
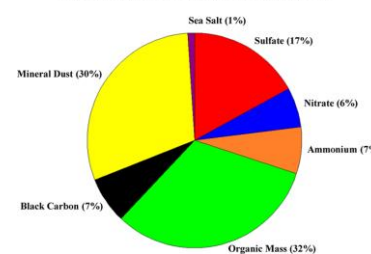
- PM_{2.5}, PM₁₀

- Speciation
 - Size distribution
 - Concentration

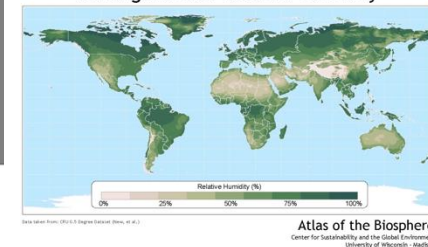
- **Meteorology**

- Temperature
 - Relative humidity

Global Population-Weighted PM_{2.5} Composition



Average Annual 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.



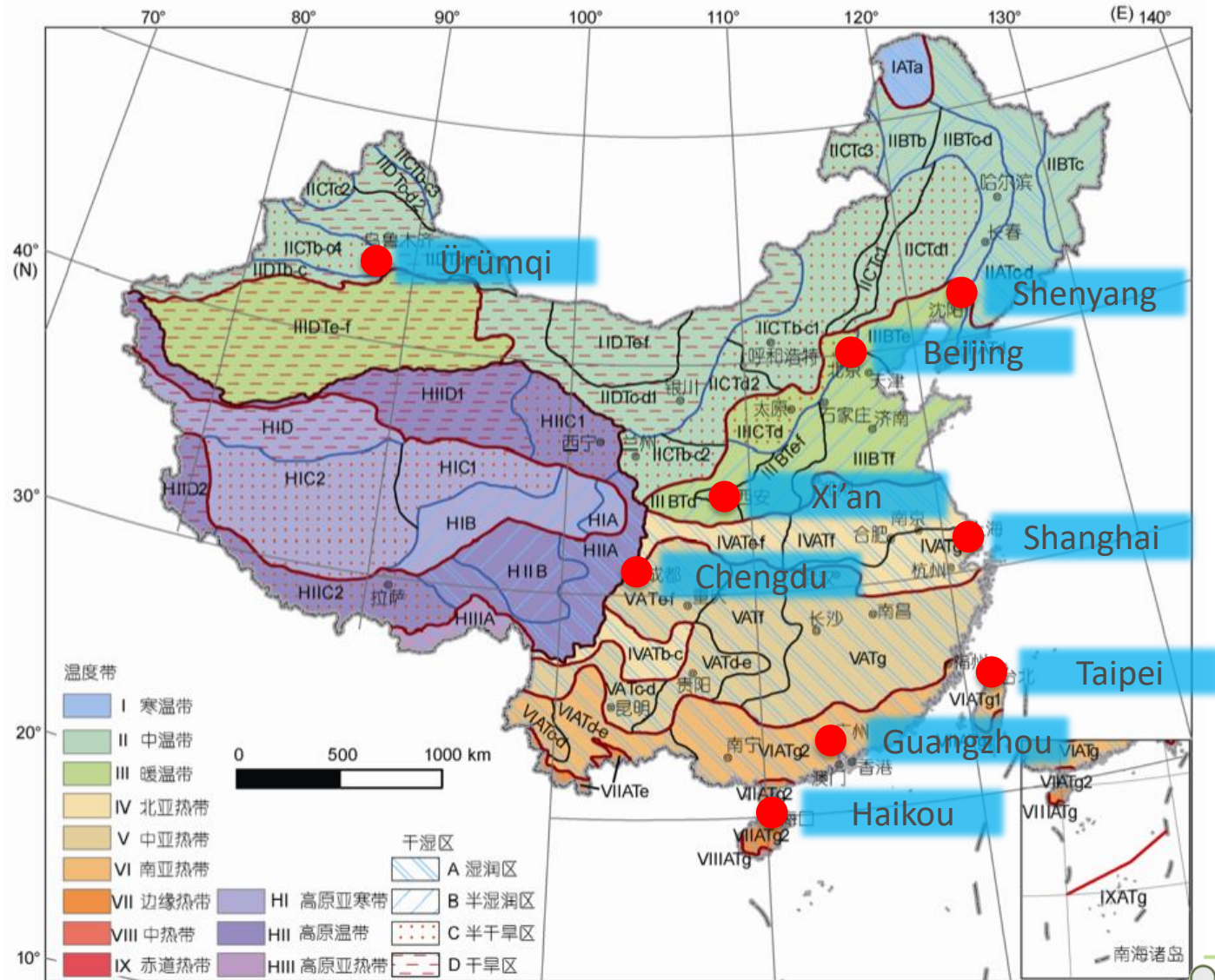
9 US Cities Represent Each Climate Region



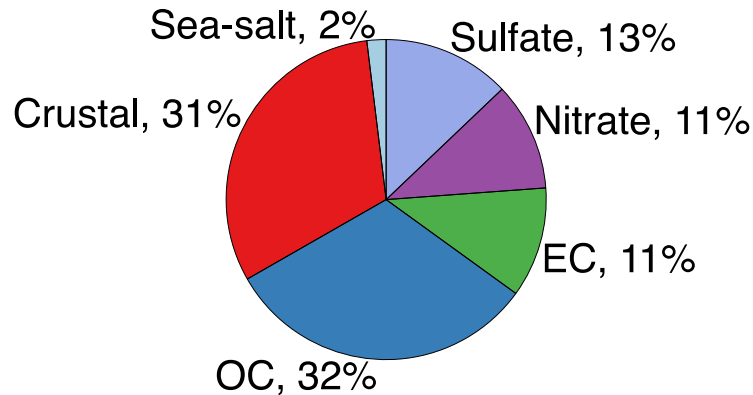
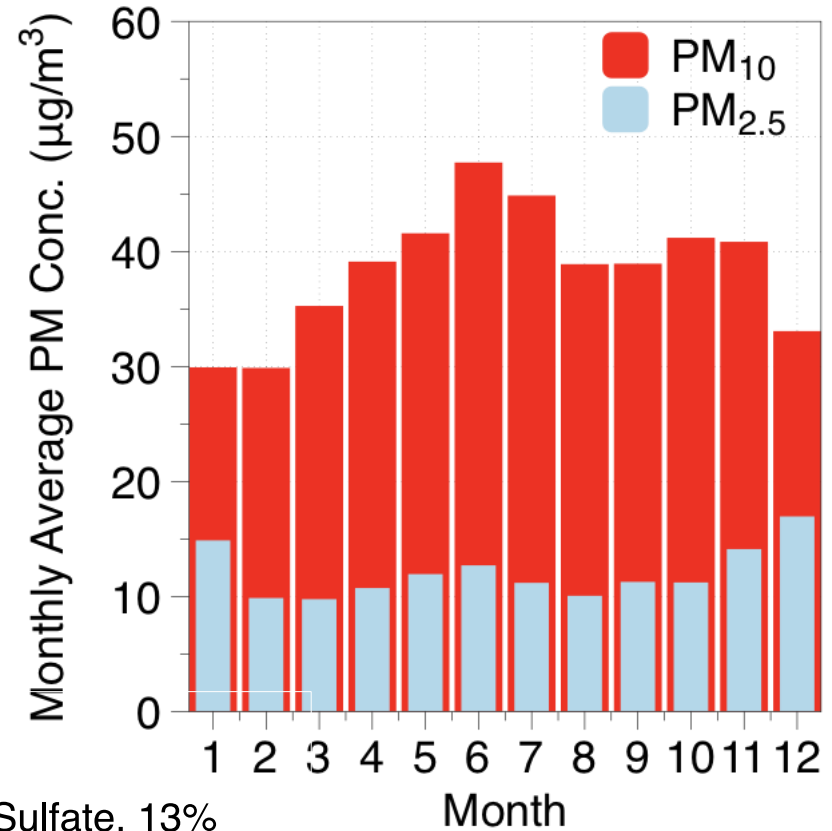
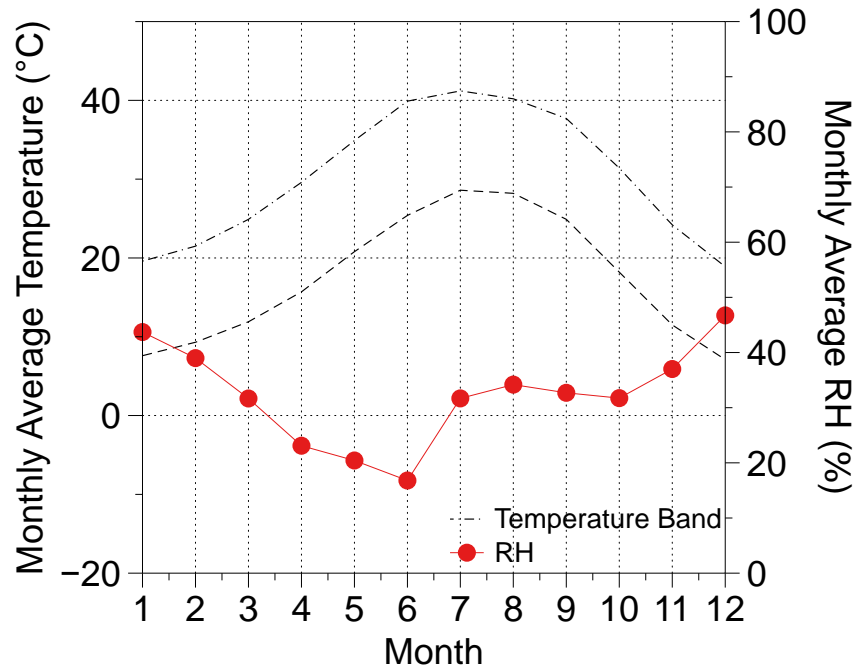
•Thomas R. Karl and Walter James Koss, 1984: "Regional and National Monthly, Seasonal, and Annual Temperature Weighted by Area, 1895-1983." Historical Climatology Series 4-3, National Climatic Data Center, Asheville, NC, 38 pp.



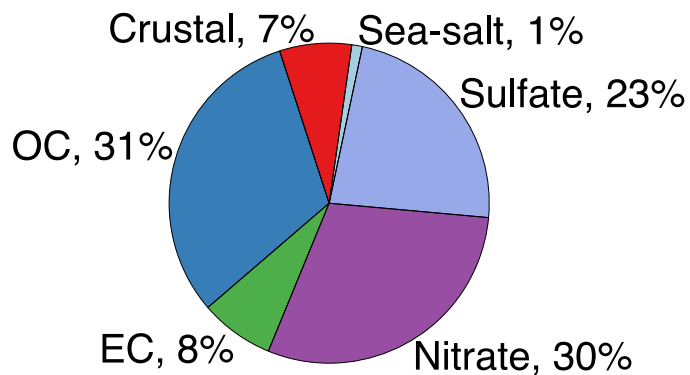
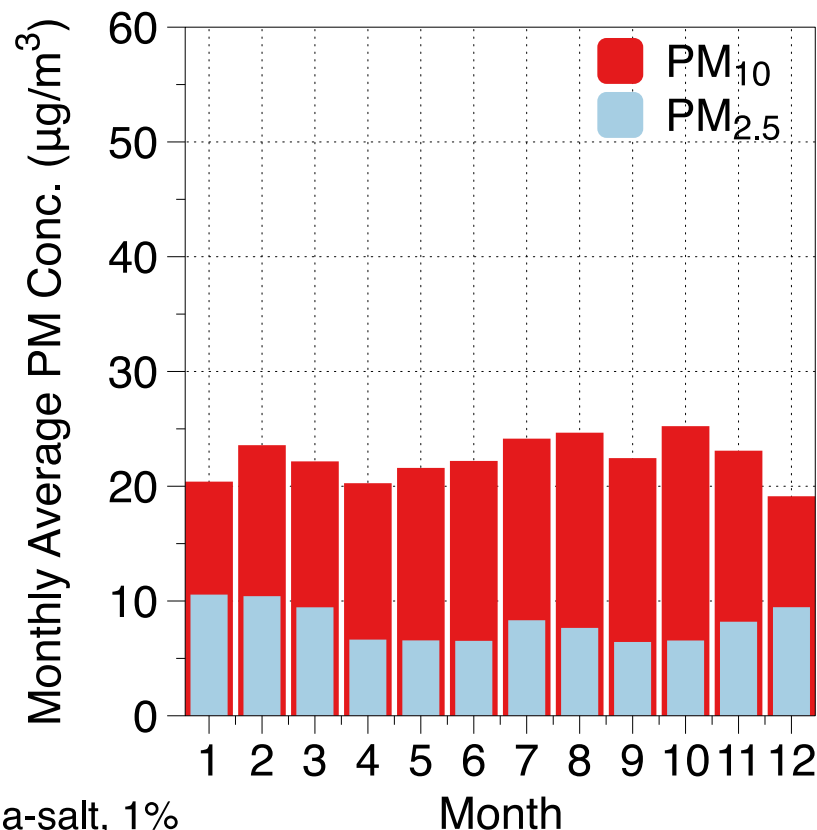
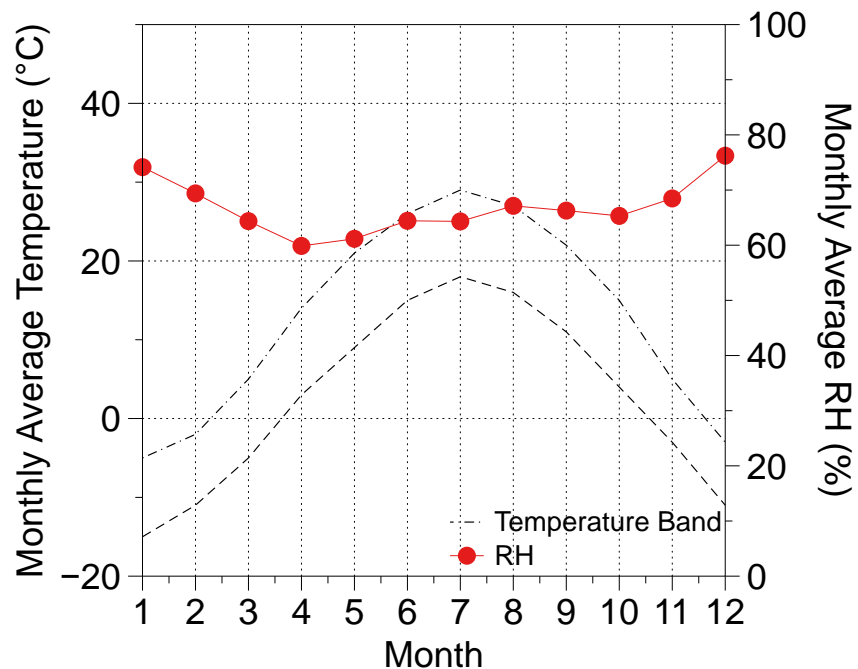
9 Chinese Cities Represents Climate Regions



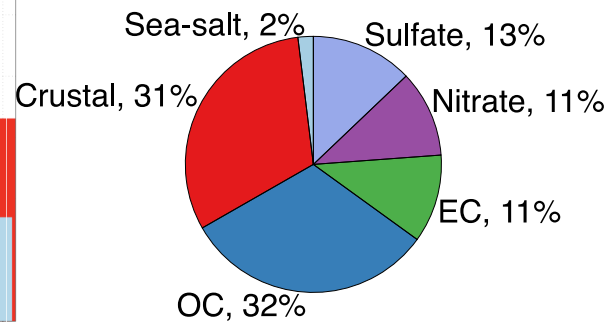
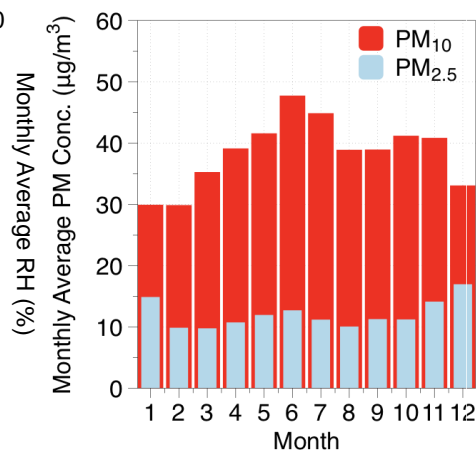
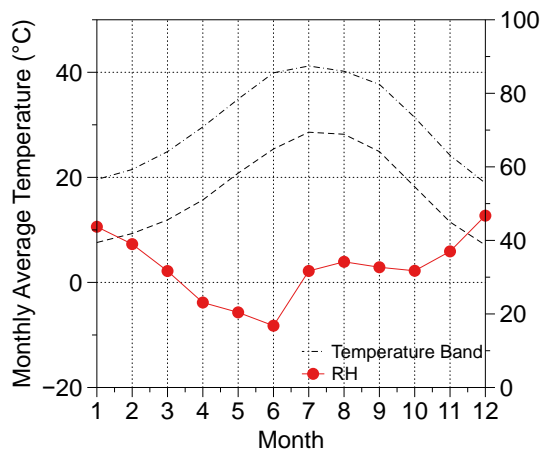
Phoenix



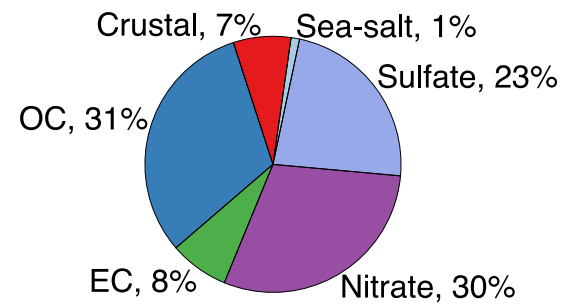
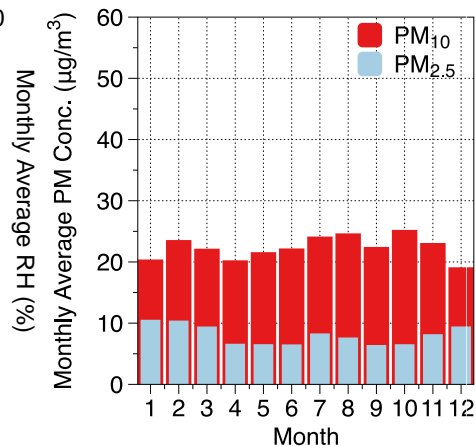
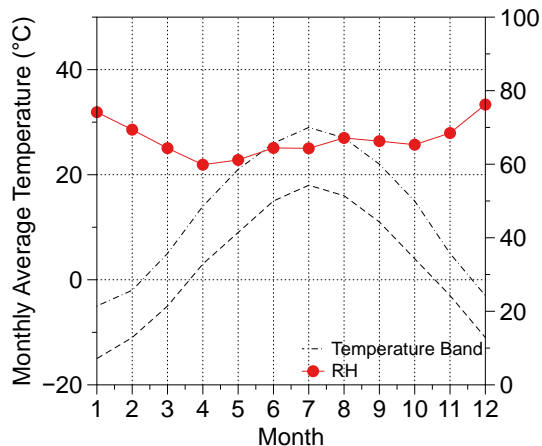
Minneapolis



Phoenix



Minneapolis



UNIVERSITY OF MINNESOTA



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



General Parameters

Gas viscosity g/cm*s

Face velocity cm/s

Atmospheric pressure Pa

Temperature K

Dust cake porosity

Estimate cake porosity ☒ [What is this?](#)

Void Function

Location ☒

Season:

Filter type:

Aerosol

% of nu

Geomet

Geomet

Particle

Dynamic

Show Pr

-----US-----

- Houston
- Los Angeles
- Minneapolis
- New York
- Orlando
- Phoenix
- Rapid City
- Seattle
- St. Louis

-----China-----

- Beijing
- Chengdu
- Guangzhou
- Haikou
- Shanghai
- Taipei
- Urumqi
- Xi'an

t diameter μm

Aerosol 2

% of number c

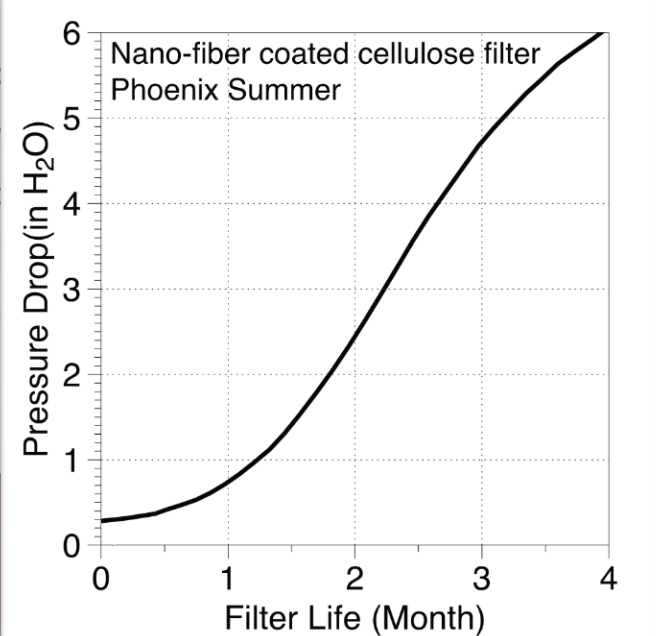
Geometric mean of v

Geometric standard c

Particle density

Dynamic shape facto

Loading Curve



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[Previous Version](#)

Start Monitor - Stop Monitor - Clear Monitor - Er

Real-Life Filter Test Rig



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**

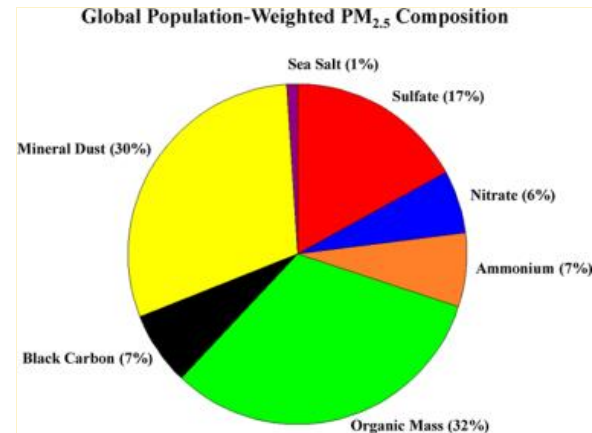
- Dust

- Salt

- NaCl
- $(\text{NH}_4)_2\text{SO}_4$
- NH_4NO_3

- Organic matter

- Soot

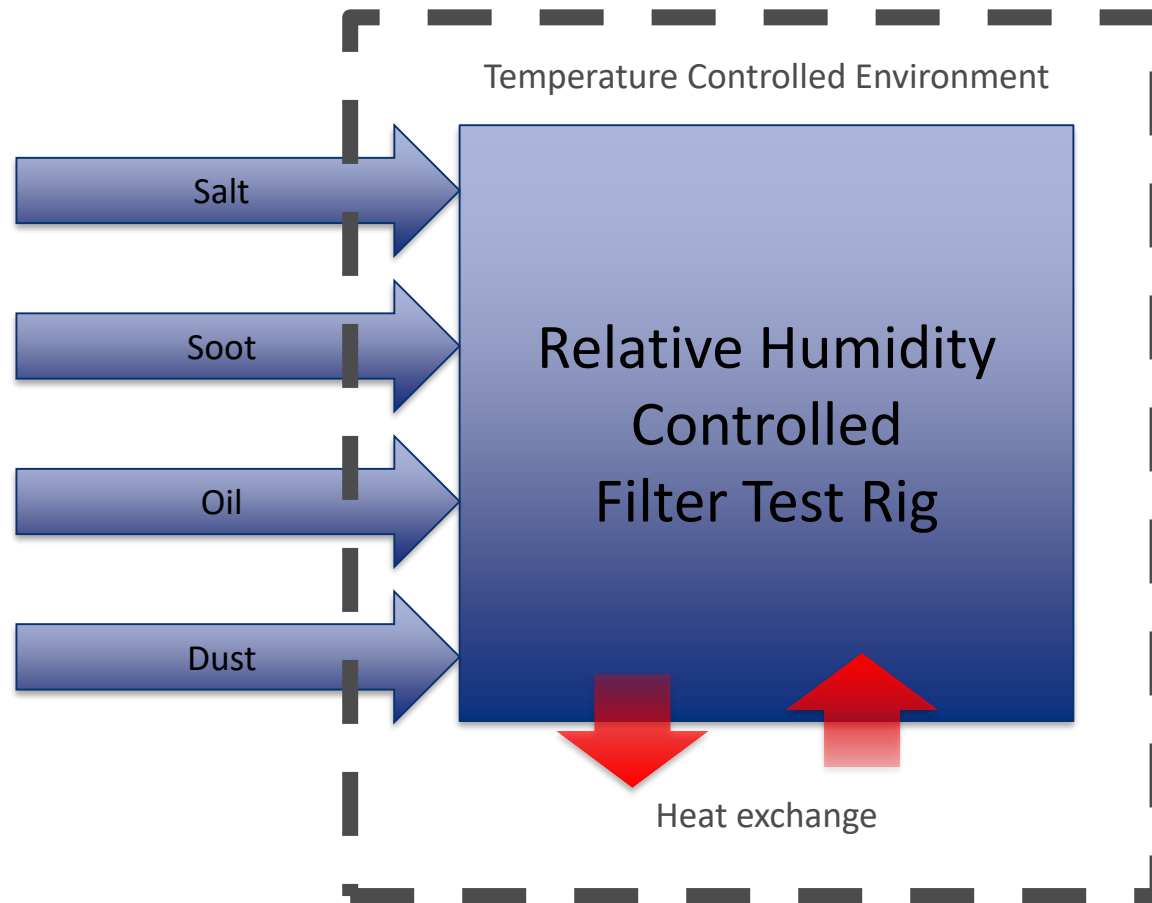


- Simulate operating environments (Temperature, RH)
- Two filter samples ($\Phi 47\text{mm}$) could be tested at the same time to **accelerate the testing process**

It is suitable to perform the laboratory research.



Real-Life Filter Test Rig Schematic



[illegible]

Temperature and RH records on the earth

Temperature		RH	
High	Low	High	Low
54 °C	-89.2 °C	100%	0.36%

Temperature and RH varies in broad range in atmosphere, however the existing test methods ignore the temperature and RH effect, especially RH

1. Constant dry compressed air is supplied to the system. A portion of the air is directly supplied into the system, another portion of the air is bubbled into the warm water to increase system RH.
2. Two RH sensors are installed at the downstream of the test filter to measure environmental RH near the test filter.

Diagram illustrating the formation of PM (Particulate Matter) from various pollutants:

- O_3 (Ozone)
- NO_x (Nitrogen oxides)
- SO_2 (Sulfur dioxide)
- CO (Carbon monoxide)
- Lead**
- PM** (Particulate Matter)

Apparatus

Temperature Controlled Environment

Relative Humidity Controlled Fiber Test Rig

Heat exchange

3. Tubed or the particle transports in insulation enclosure are stainless steel for the heat exchange.



Two 350 W heaters are installed in the enclosure.

- A radiant heat exchanger coupled chiller is used to cool the

Acknowledgement

The following are the support of members of the C Research: 3M, A. G. Smith, Applied Materials, BASF Co. Company, Calsonic, Filtration, Donaldson Company, Ford Motor Company, MSP Corporation, Sanyo, B. Shigemasa, W. H. Co. Ltd., TSI Inc., W. L. Gore, Shengda Filter Technology Co. Ltd., Wei Tian Filter Ltd., Yancheng Environmental Protection Science and the other member National Institute for Occupational Health (NIOSH).

Real-life Filter Loading Test Rig

Chaining PM, Quoting O₃, O₂, CO₂ & H₂O

Particle Technology Laboratory, University of Birmingham

Introduction

The development and selection of air filters are often used in laboratory filter tests, which usually utilize a high blend of testing particles in a single environment. However, in the field, filters may not be exposed to the environment prior to the lab test conditions. The performance of air filters could depend on variations in pollutant composition, working temperature and relative humidity. Current filter test methods may not mimic the different working scenarios, including different pollutant composition, working temperature and relative humidity. Therefore, a test rig would help us understand the effect of these factors if it could generate different types of the air pollutants and control the filter testing temperature and relative humidity.

PM composition includes decahlorobiphenyls (PCBs), organic matter (VOCs), and inorganic matter (minerals). PM composition is not uniform and varies in the environment.

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Introduction

Temperature and RH records on the earth

Temperature	RH
High	Low
Low	High
54 °C	89.2 °C
100%	0.94%

Temperature and RH varies in broad range in atmosphere, however the existing test methods ignore the temperature and RH effect, especially RH.

Apparatus

Temperature Controlled Environment

Relative Humidity Controlled

Heat exchange

The real-life filter loading test rig is a RH controlled filter test rig enclosed in a temperature controlled

environment.

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Apparatus

1. Constant dry compressed air is supplied to the system. A portion of the air is directly injected into the system, another portion of the air is bubbled into the warm water to increase system RH.

2. Two RH sensors are installed at the upstream and downstream of the test filter to measure environmental RH near the test filter.

3. Tubes for the particle transportation into the test filter are stainless steel to the heat exchange.

4. Two 350W heaters with fans are installed in the enclosure to maintain the temperature.

5. A radiator heat exchanger is coupled with a chiller to cool the air.

6. 3 pairs of fans are used to circulate the air in the enclosure.

7. The test filter is mounted on a motorized turntable to rotate the filter during the test.

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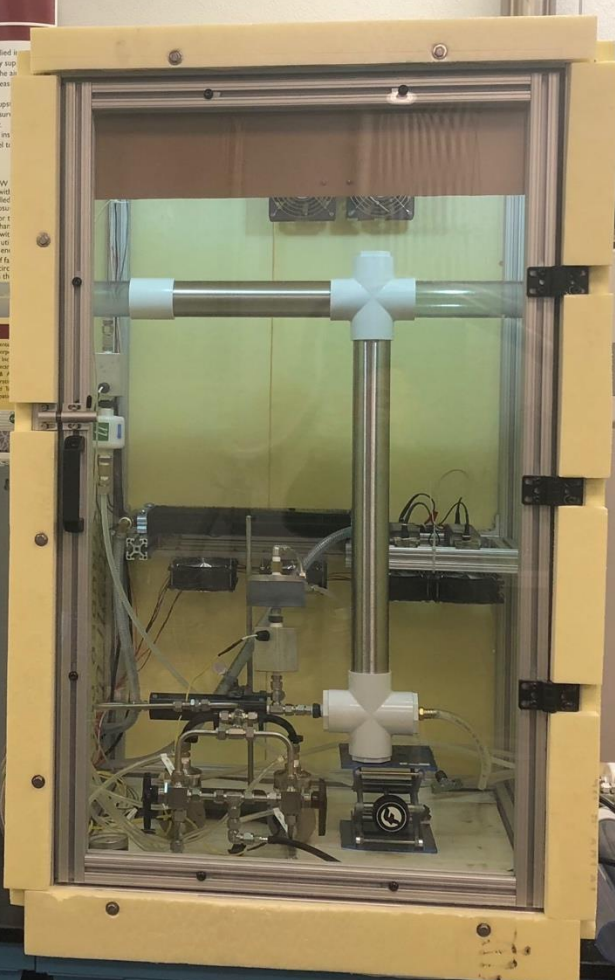
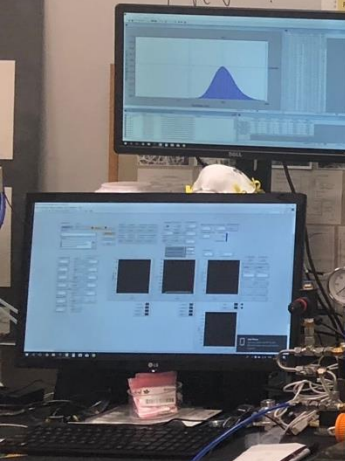
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The authors would like to thank the members of the Centre for Filtration Research, University of Birmingham, for their support and assistance during the development and testing of the test rig. The authors would also like to thank the members of the Particle Technology Laboratory, University of Birmingham, for their support and assistance during the development and testing of the test rig.

Center for Filtration Research



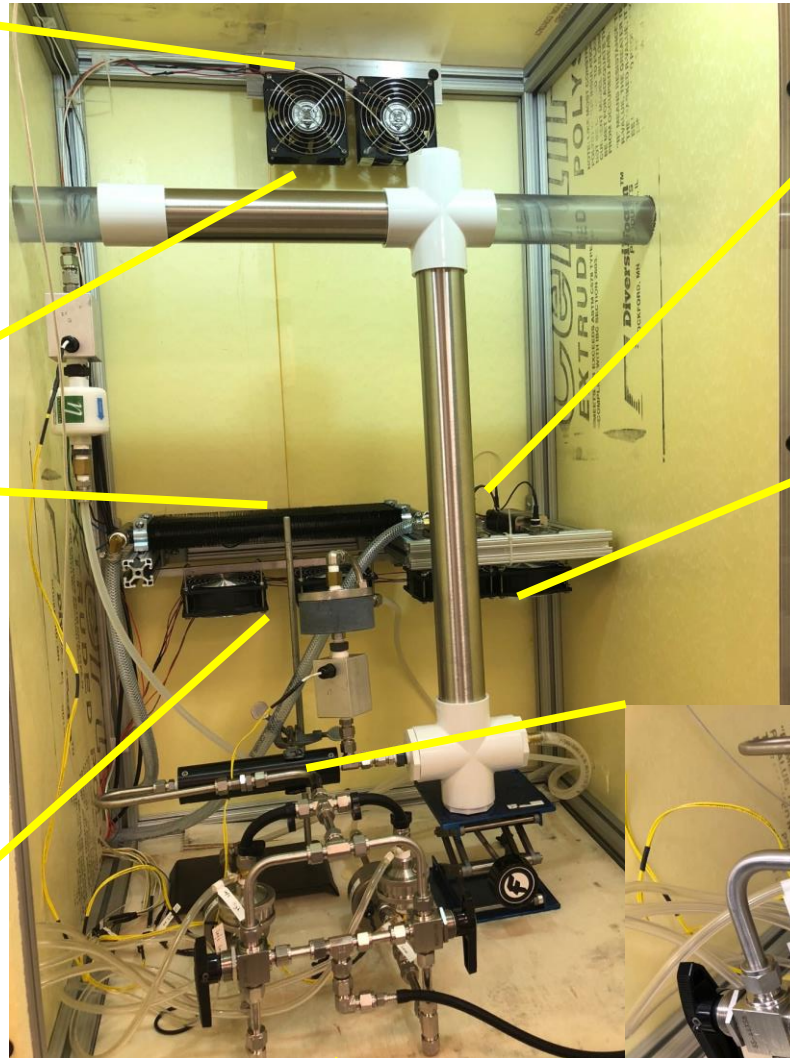
Details of the filter test rig



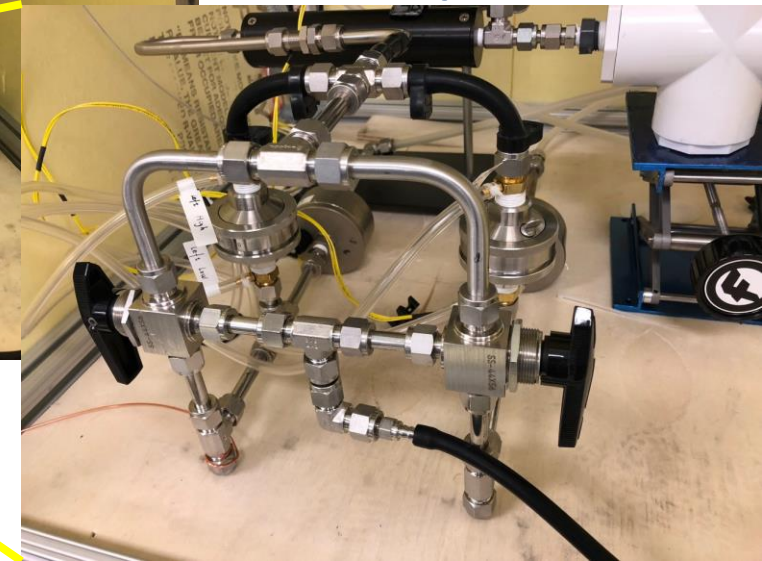
Circulating Fans



Cooling Coil & Fans



Heating Elements & Fans



Two-sample holder

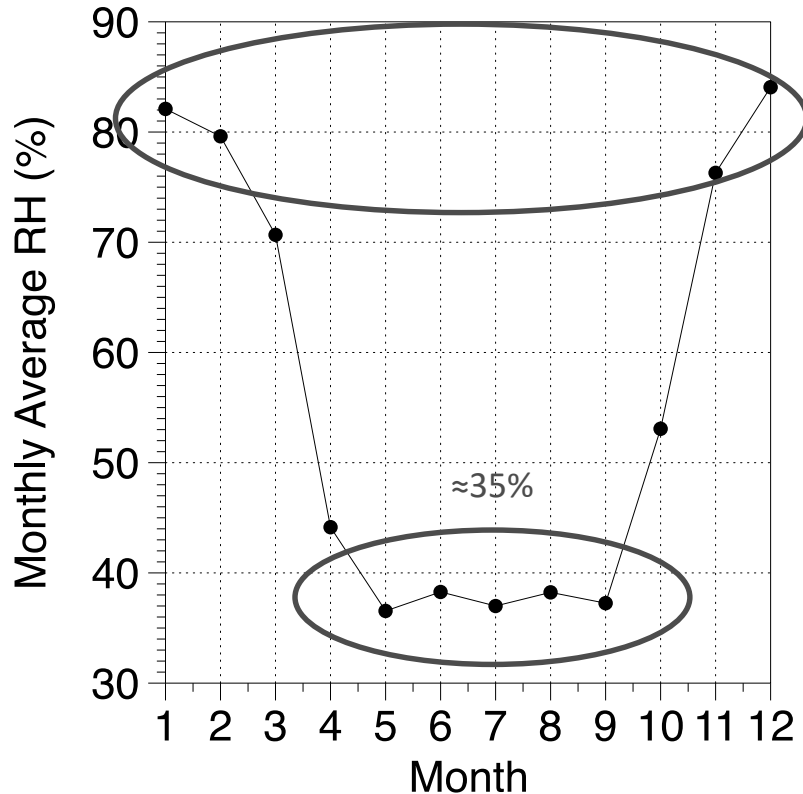
Case Study

RH & PM_{2.5}/PM₁₀ percentage

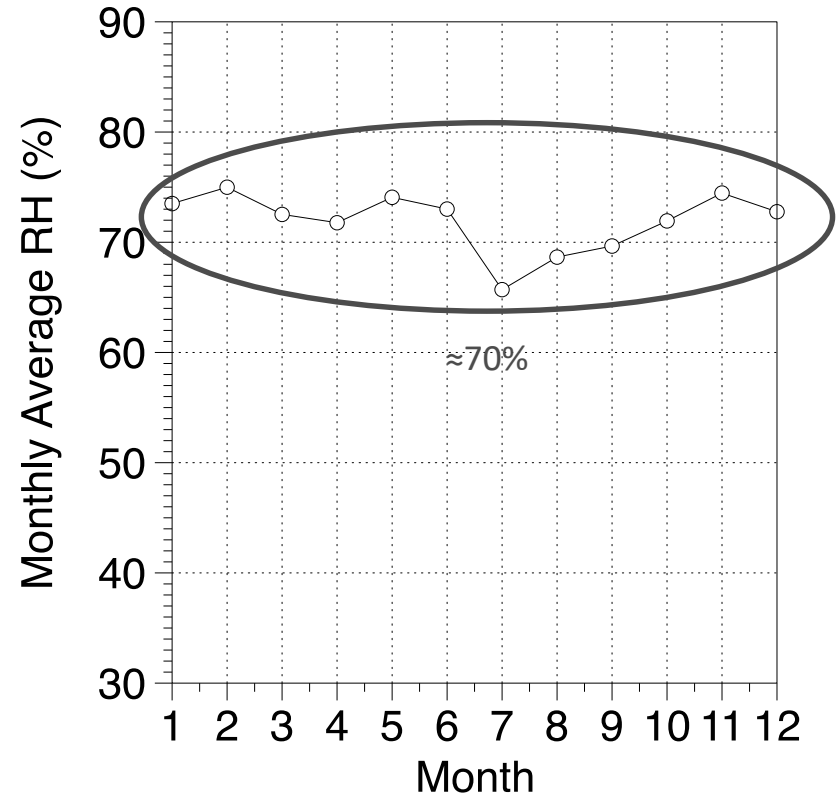


Temporal and Spatial Variation of RH

Urumqi



Taipei



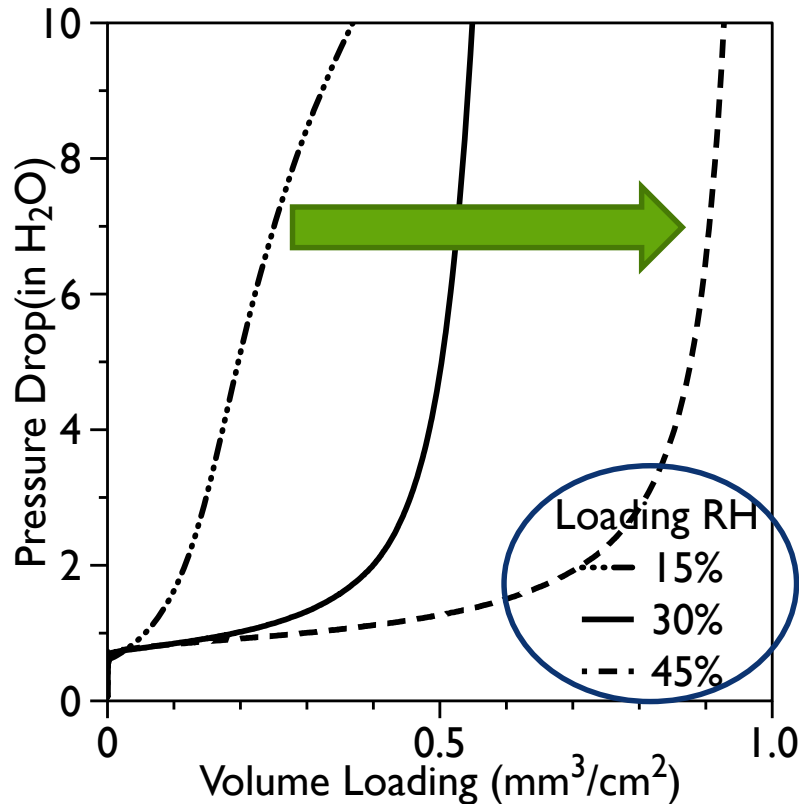
Summer: Urumqi RH≈35% Taipei≈70%



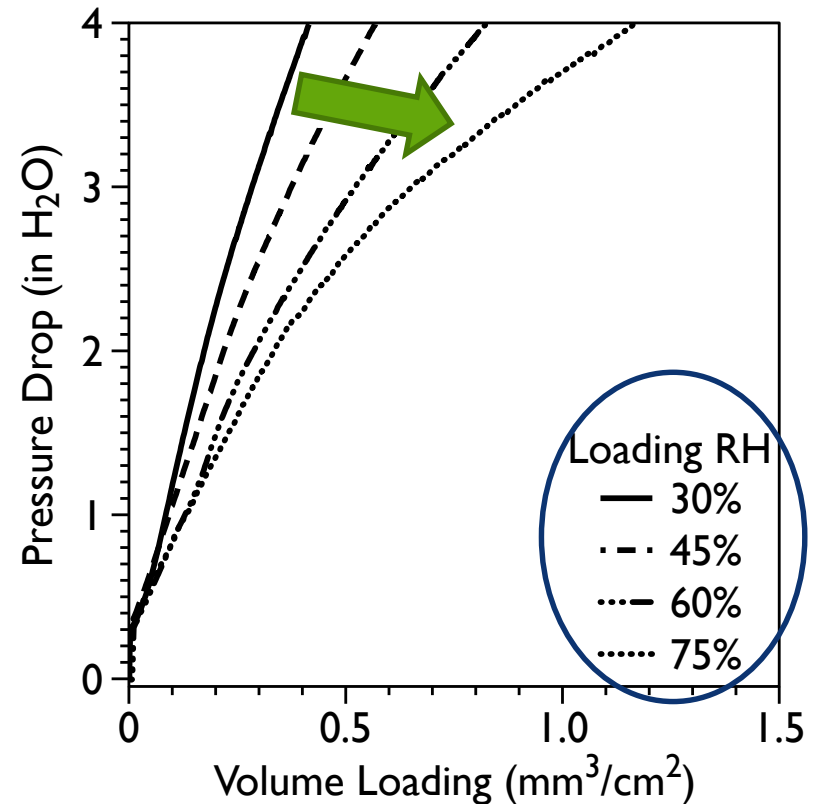
Loading Curves of Various RHs

Summer: Urumqi RH≈35% Taipei≈70%

Cellulose Filter
 NH_4NO_3



Nano-fiber Coated Cellulose Filter
 $(\text{NH}_4)_2\text{SO}_4$



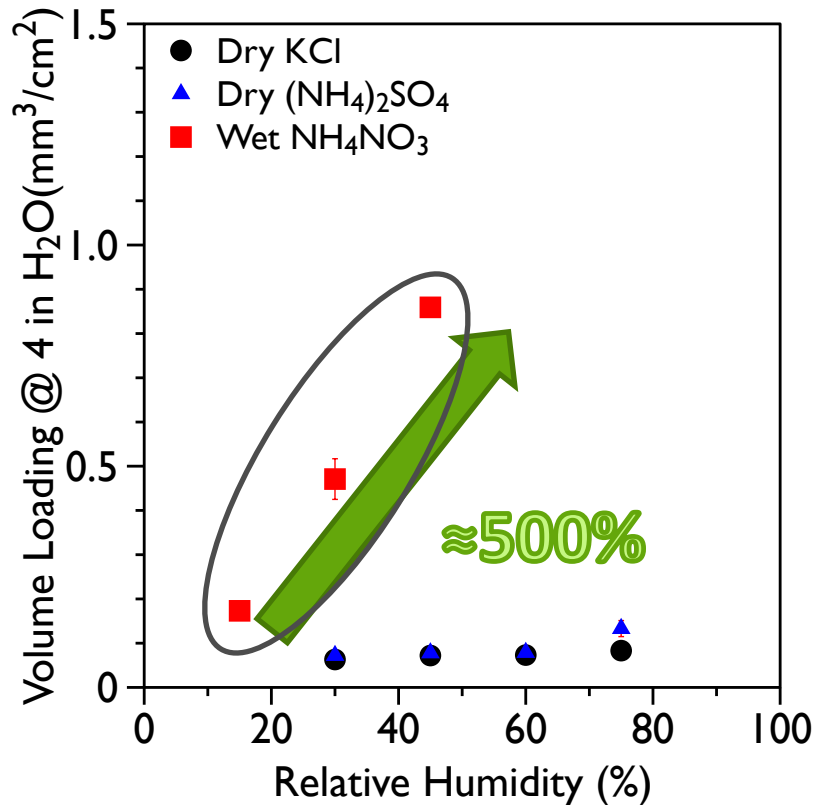
Loading behavior is RH dependent



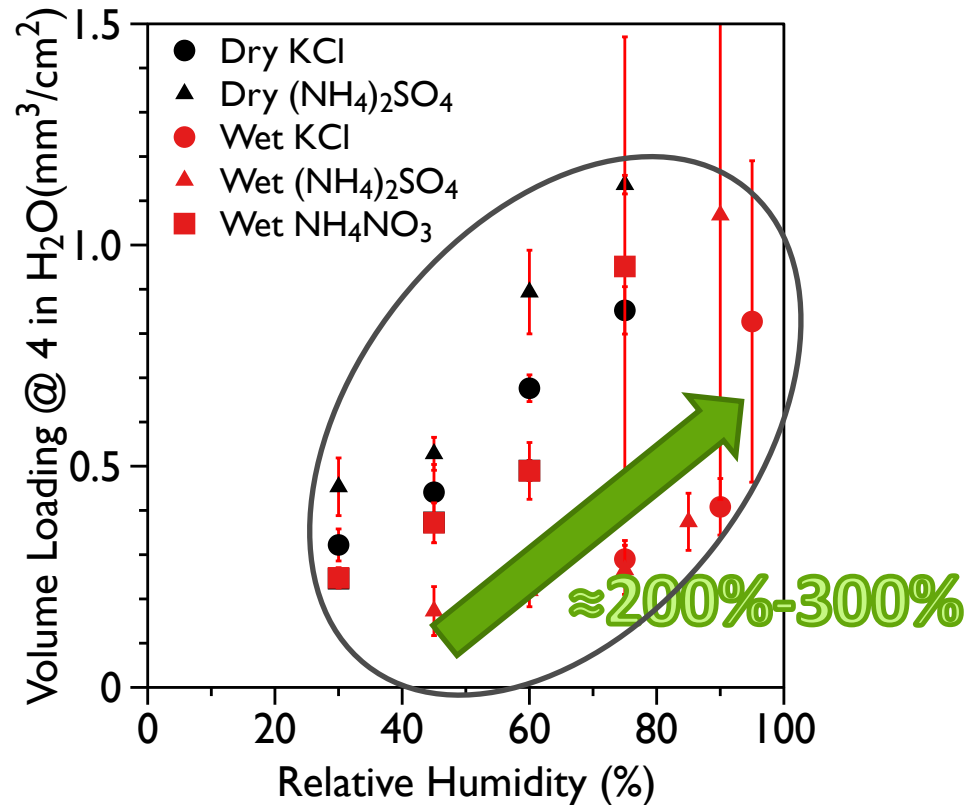
Volume Loading of Two Types Filter Under Different RHs

Summer: Urumqi RH \approx 35% Taipei \approx 70%

Cellulose Filter



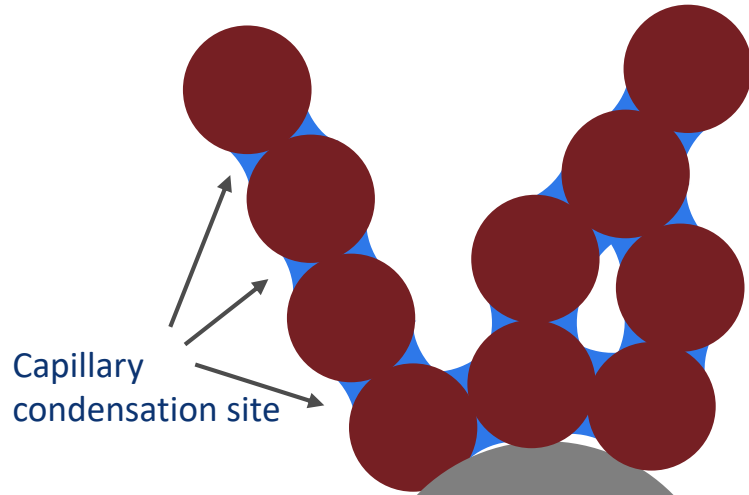
Nano-fiber Coated Cellulose Filter



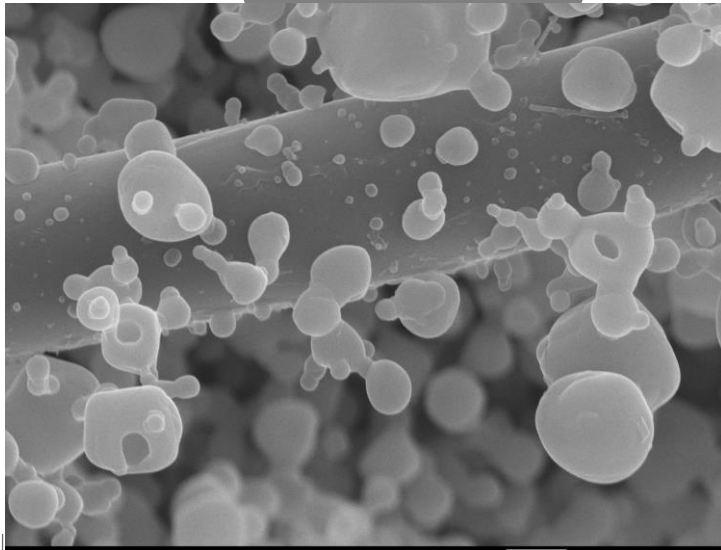
Generally, higher loading RH could cause higher holding capacity.



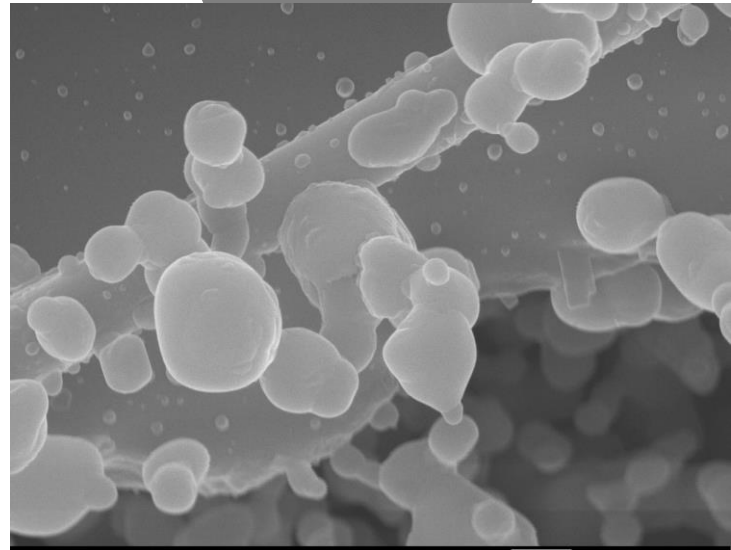
Water could affect the morphology of dendrites



KCl 30%RH

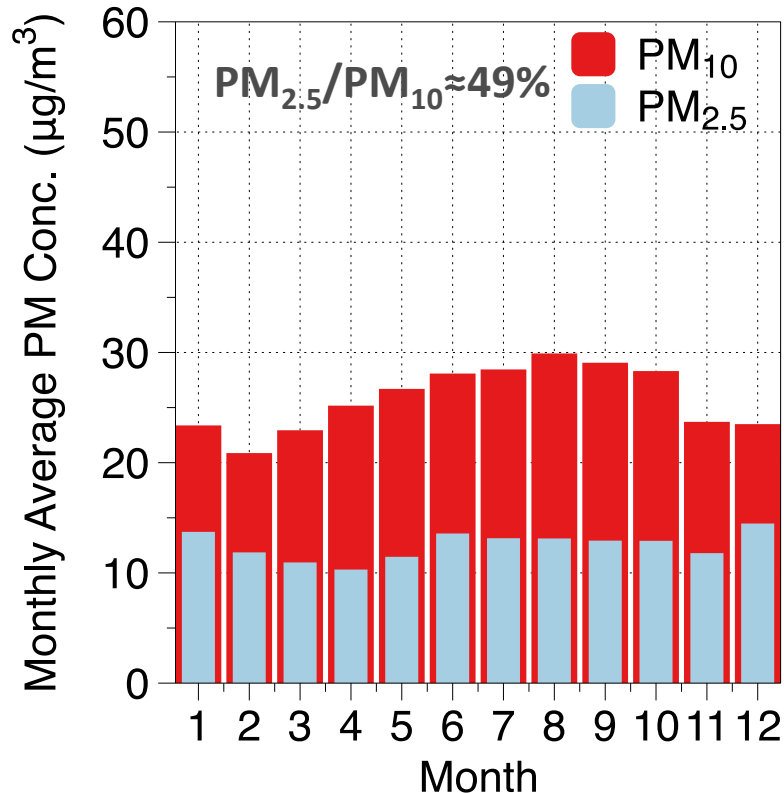


KCl 5%RH

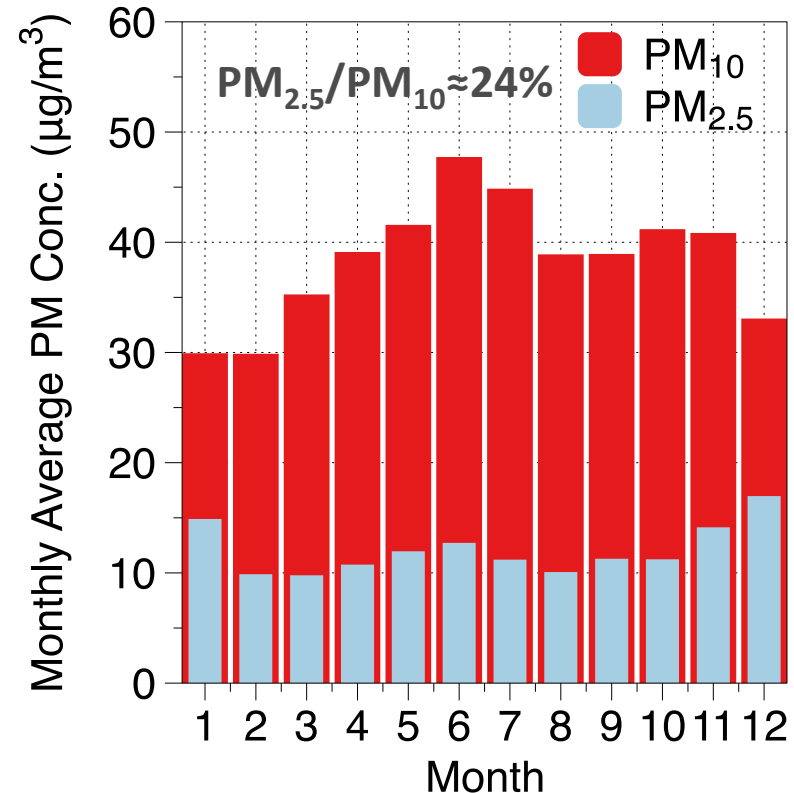


PM_{2.5}/PM₁₀ Percentage

Los Angeles



Phoenix



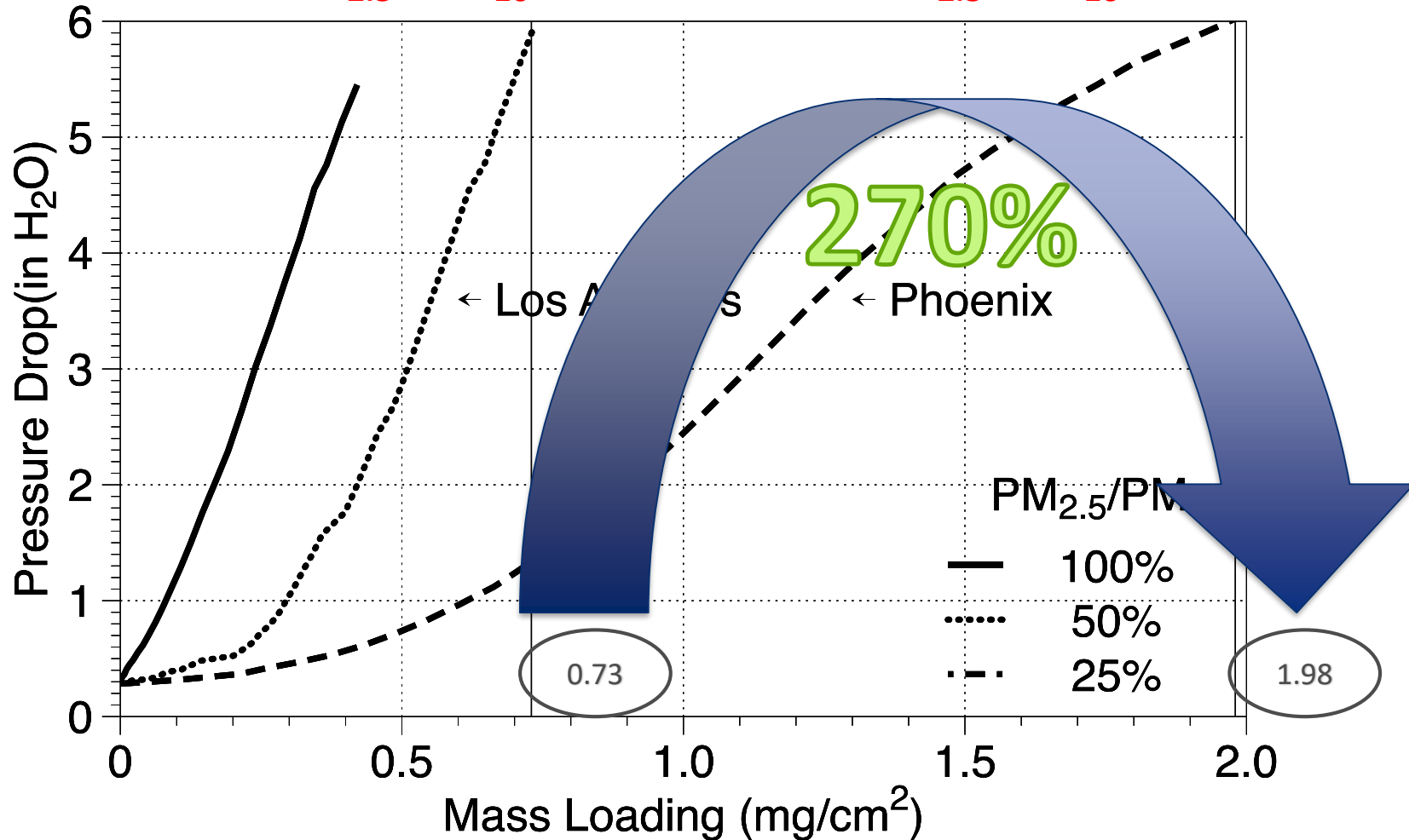
Los Angeles
Phoenix

PM_{2.5}/PM₁₀ ≈ 49%
PM_{2.5}/PM₁₀ ≈ 24%



Loading Curves of Different PM_{2.5}/PM₁₀ Percentage

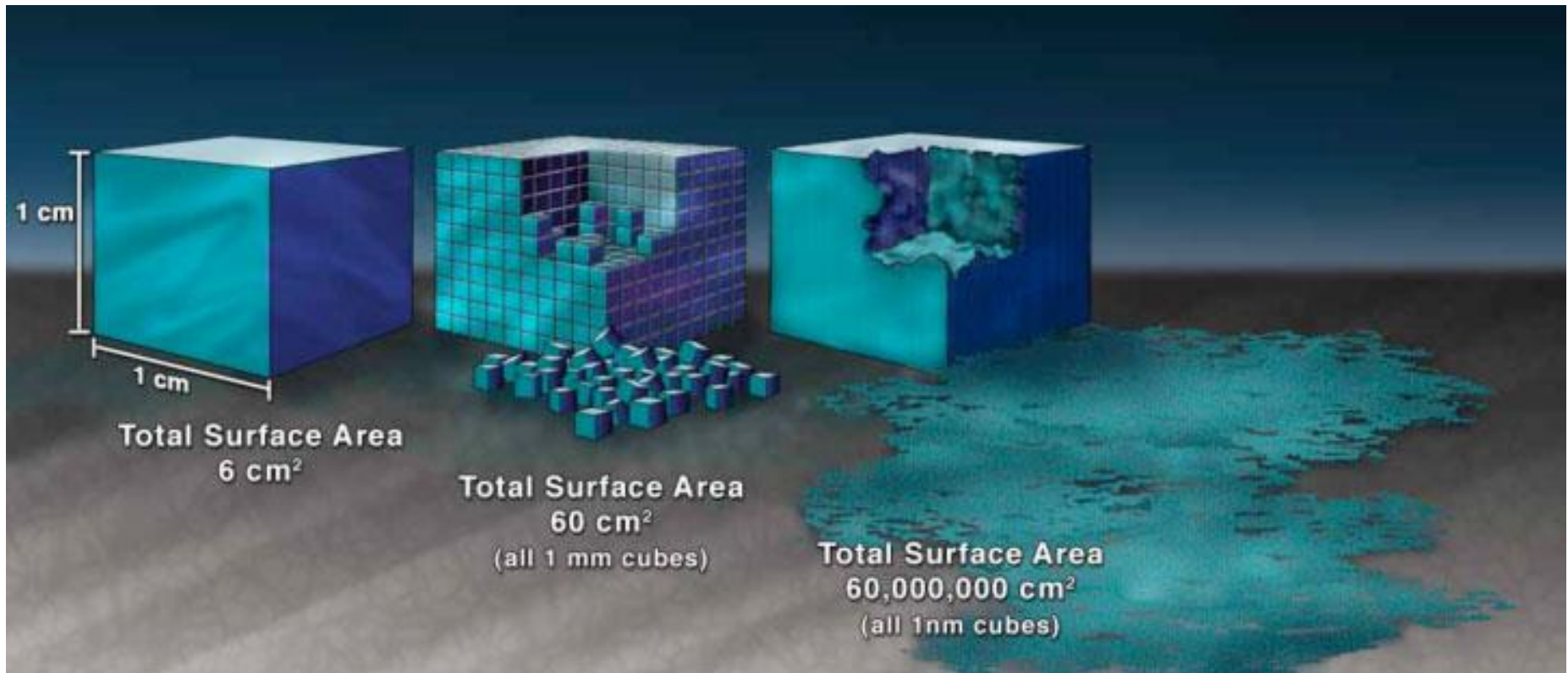
Los Angeles PM_{2.5}/PM₁₀≈49% Phoenix PM_{2.5}/PM₁₀≈24%



Generally, higher Coarse portion
could cause more holding capacity.



Particle size could affect the cake resistance



Smaller particles could cause more resistance by increasing surface area



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.**
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