Particle effective densities and size distributions in vehicular and wood combustion exhaust emissions: Implications to particle deposition in the human respiratory system

Arya Mukherjee, ETH Nanoparticles Conference 2022

Experimental Setup

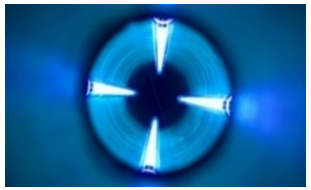
Particle density & morphology measurements

Car exhaust emissions

Small scale wood combustion

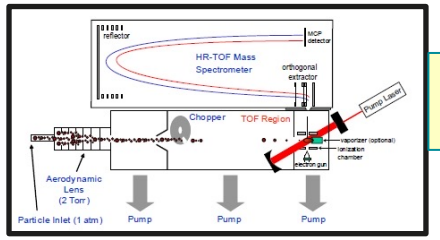
Diluting

Sampling



Oxidation flow reactor (PEAR)

Aerosol Mass Spectrometer (AMS)

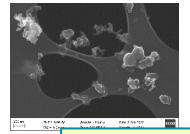


Chemical composition

Aethalometer

Residence chamber

SEM/TEM



morphology

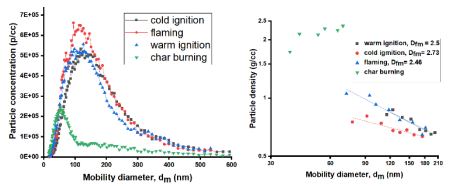
Neutralizer

APM

DMA

CPC

Particle size distribution



Particle effective density

Vehicle & driving settings

Test phase	min	seconds	Speed	Gear
1	5 min	300	Cold idle	-
2	15 min	900	50 km/h	4
3	15 min	900	100 km/h	5
4	15 min	900	80 km/h	5
5	10 min	600	Warm idle	-

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- Vehicle: Skoda Scala (2021)
- Fuel: Gasoline (95E10)
- Emission after-treatment: EURO6, 3-way catalyst & GPF

Summary of wood combustion emission measurements

Ignition (warm and cold)

Flaming phase

Char Burning phase

Fresh emissions and photochemically aged particles of these four burning phases were investigated

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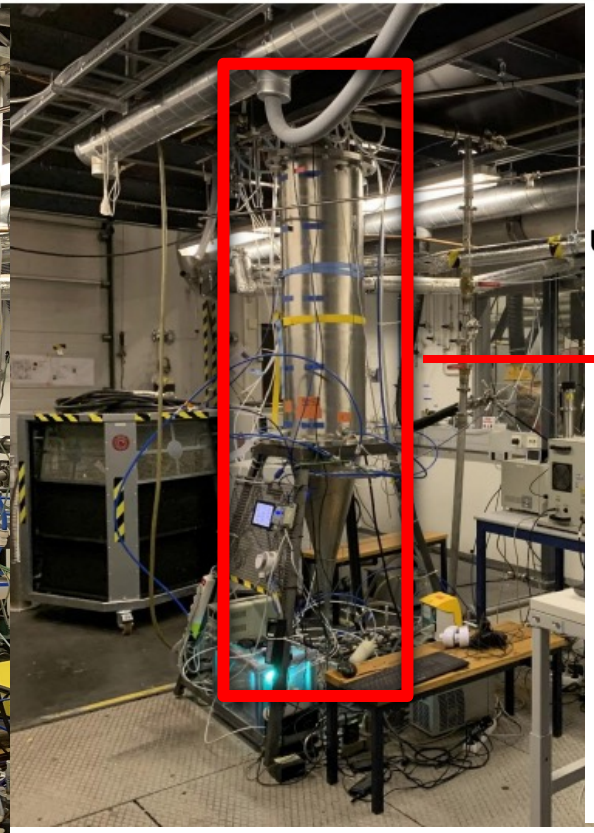
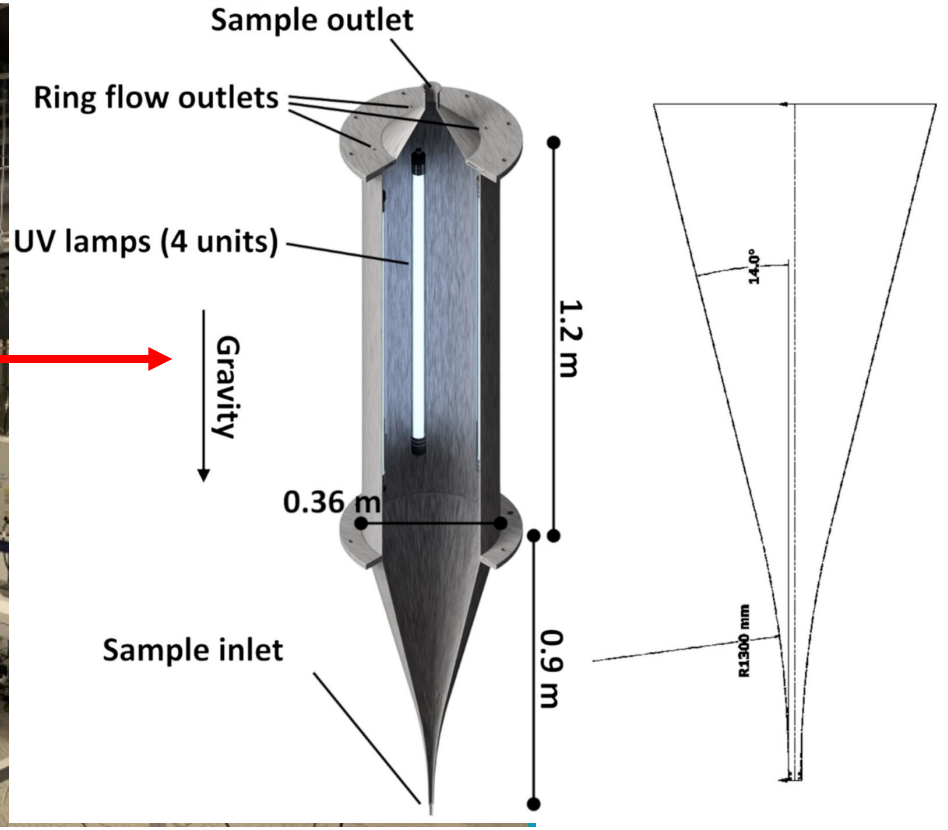
Photochemical Emission Aging flow tube Reactor (PEAR)





Experimental setups at the ILMARI-laboratory:
A SKODA SCALA vehicle on a chassis dynamometer
in connection with the high-volume PEAR oxidation flow reactor

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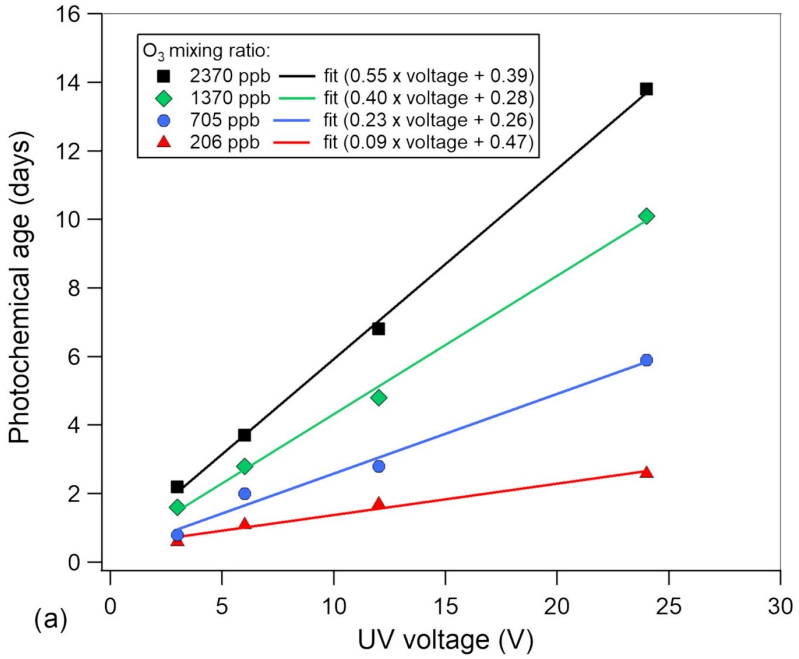
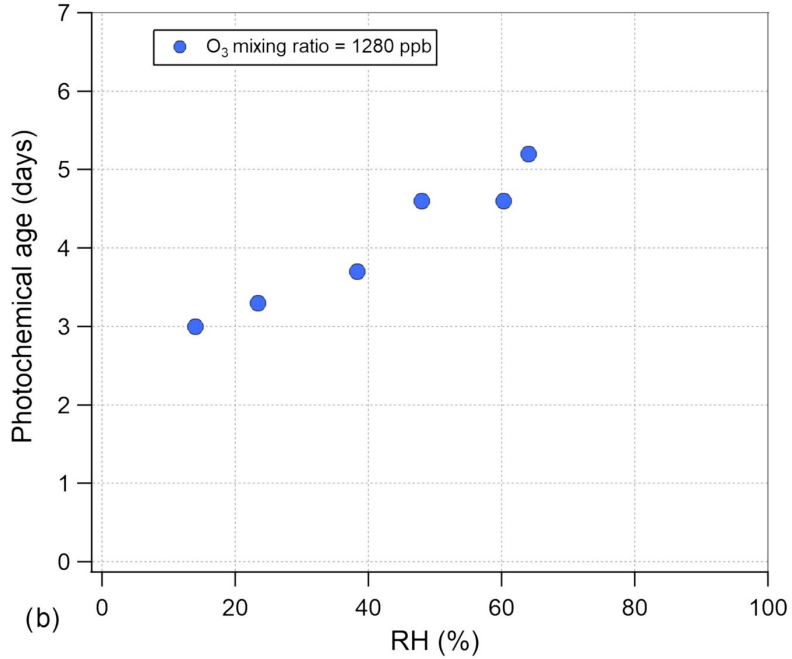
Oxidation process in PEAR



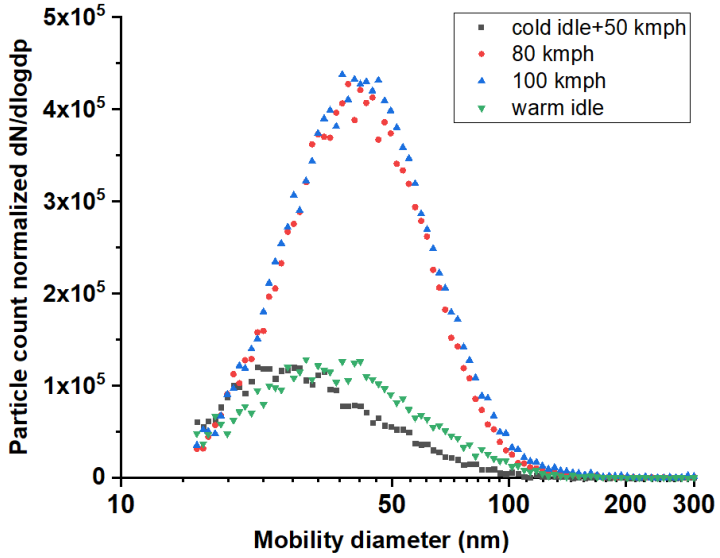


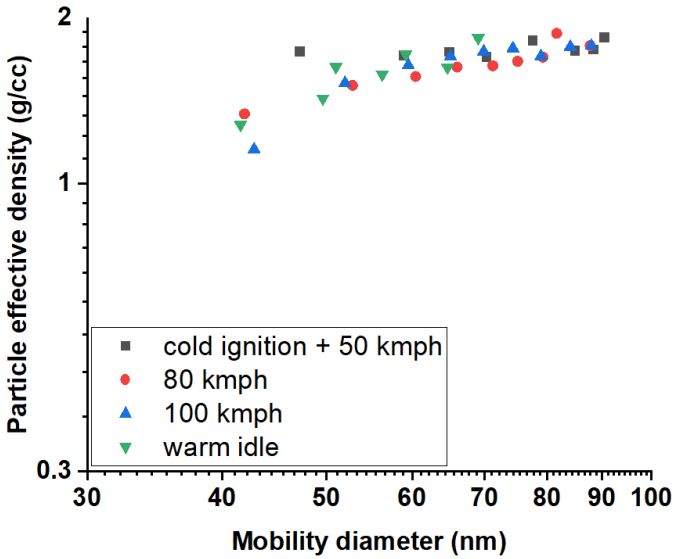
$$O_3 + UV\,(254\,nm) \rightarrow O(^1D) + O_2 \qquad (1)$$

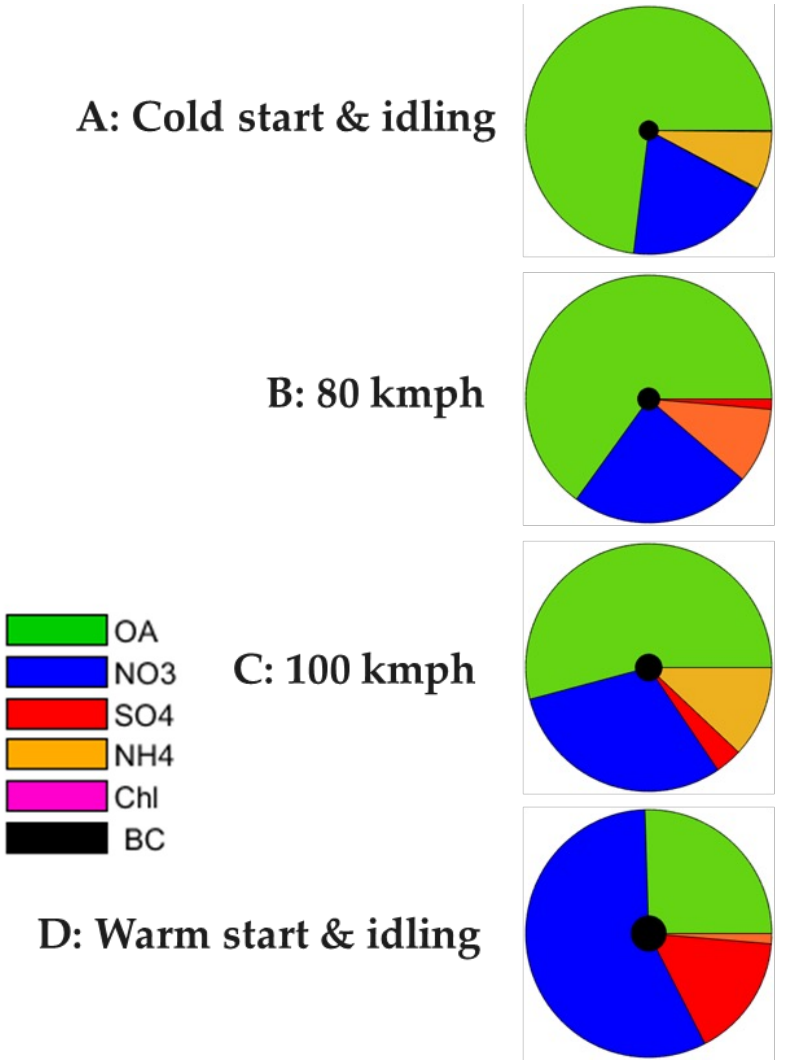
$$O(^1D) + H_2O \rightarrow 2\ OH \qquad (2)$$

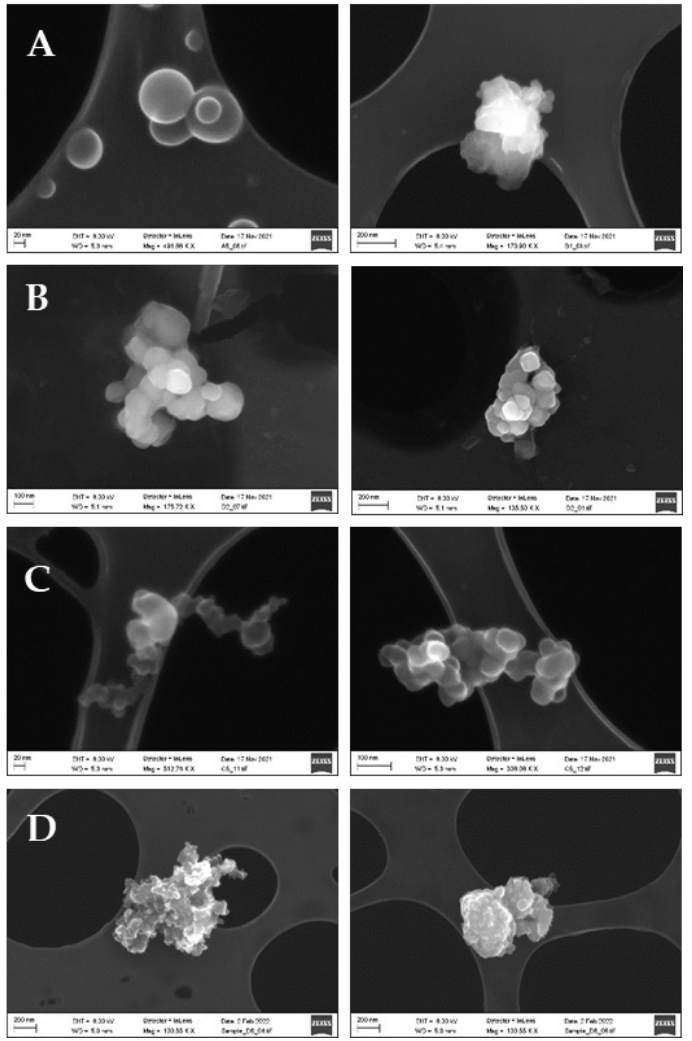
Results

Effects of photochemical aging on particle effective density & morphology

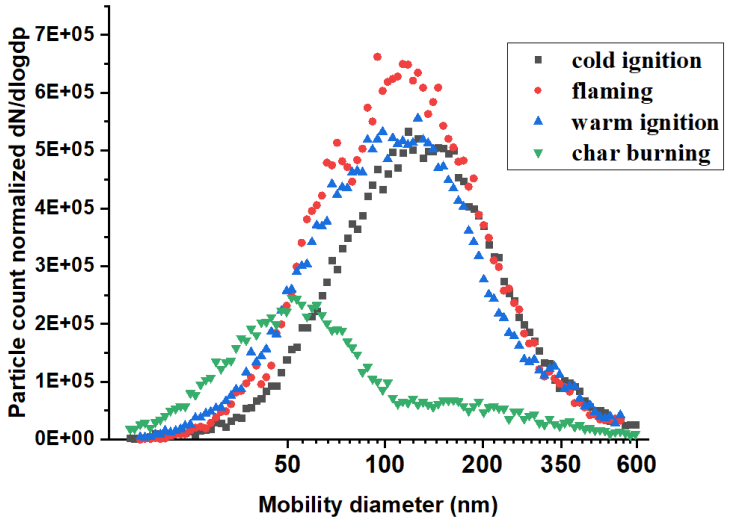


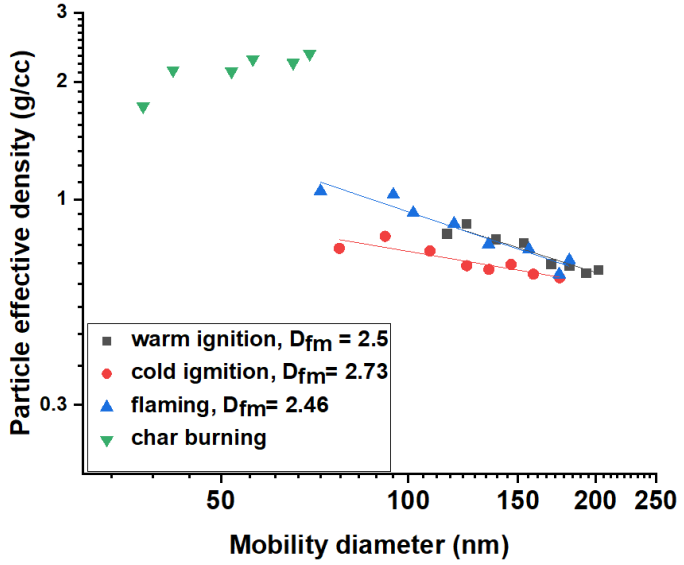






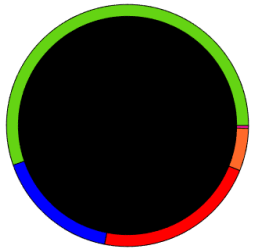
Effects of photochemical aging on particle effective density & morphology



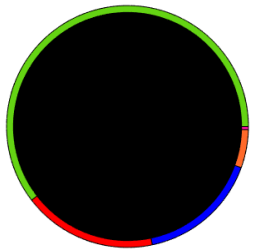


A. Cold ignition

B. Warm ignition

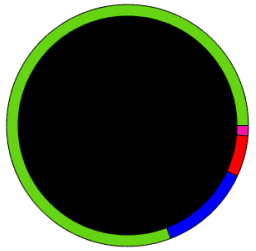


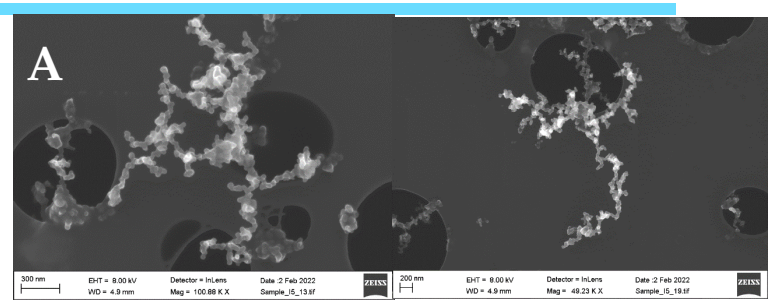
C. Flaming

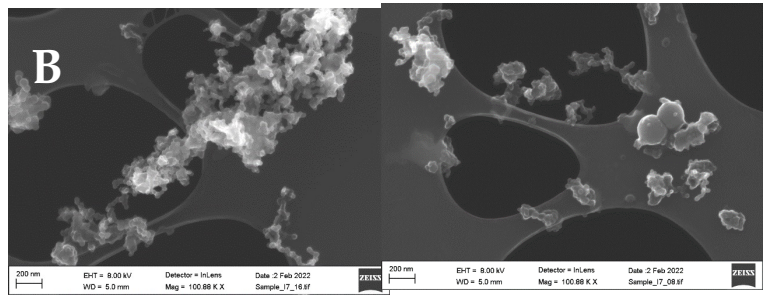


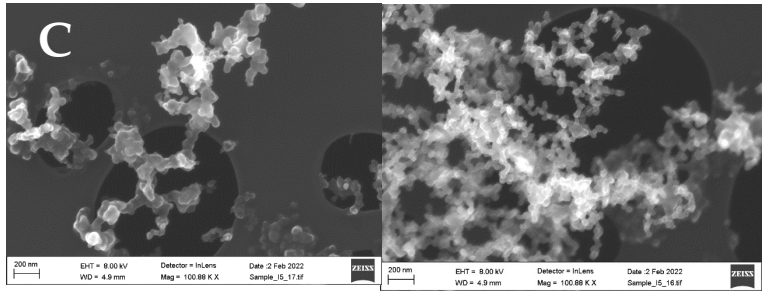
OA
NO3
SO4
NH4
Chl
BC

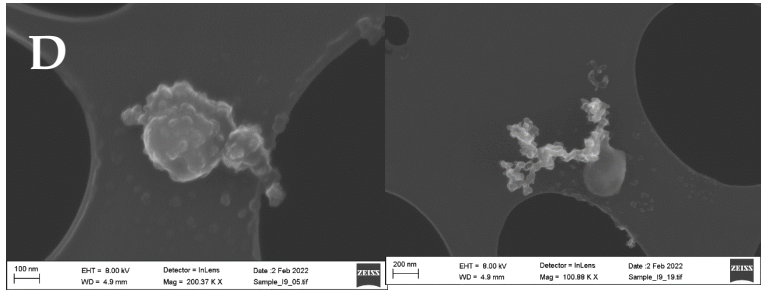
D. Char burning











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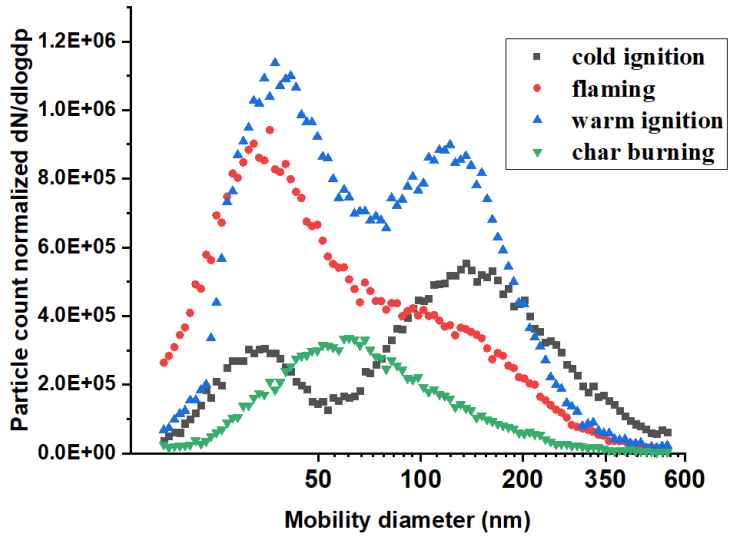
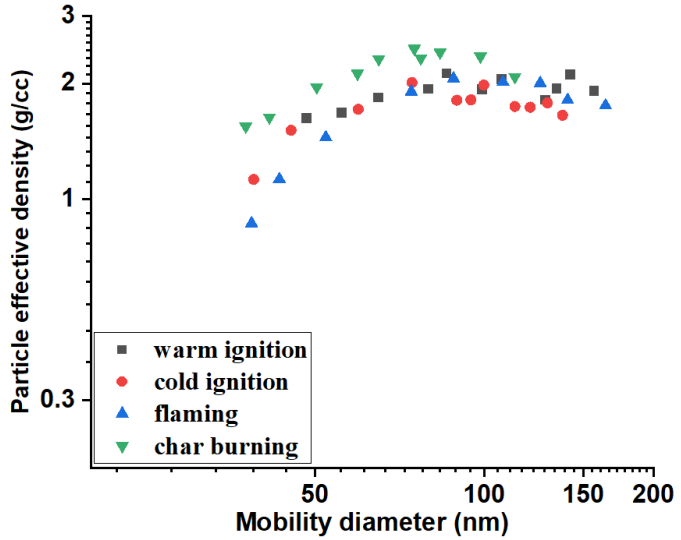
Effects of photochemical aging on particle effective density & morphology





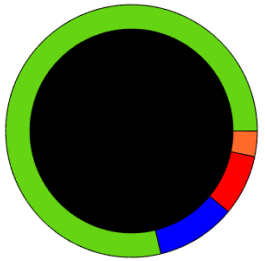
A. Cold ignition

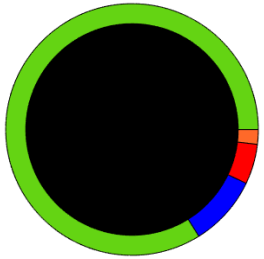
B. Warm ignition

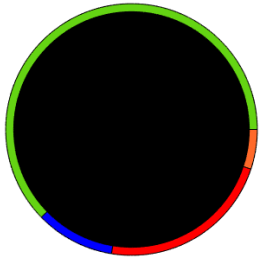
C. Flaming

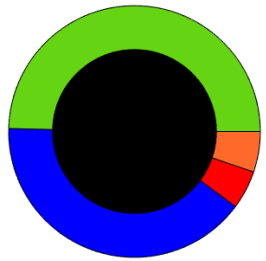
OA
NO3
SO4
NH4
Chl
BC

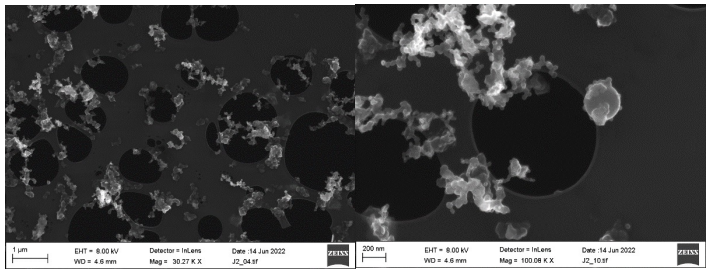
D. Char burning

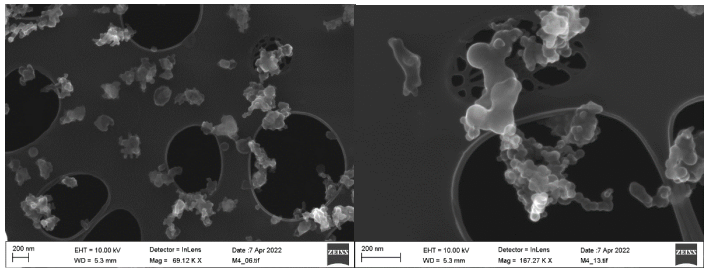


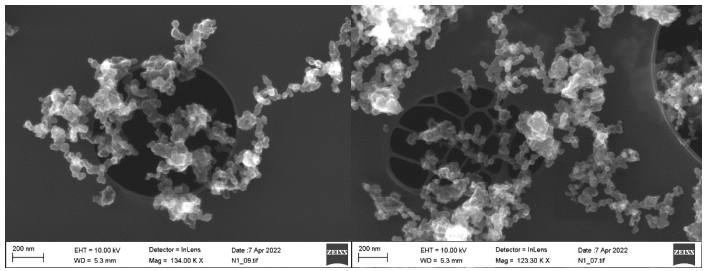


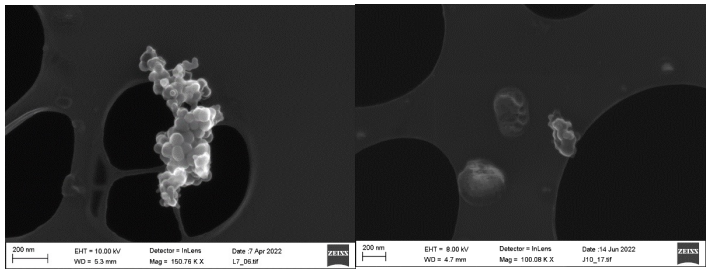


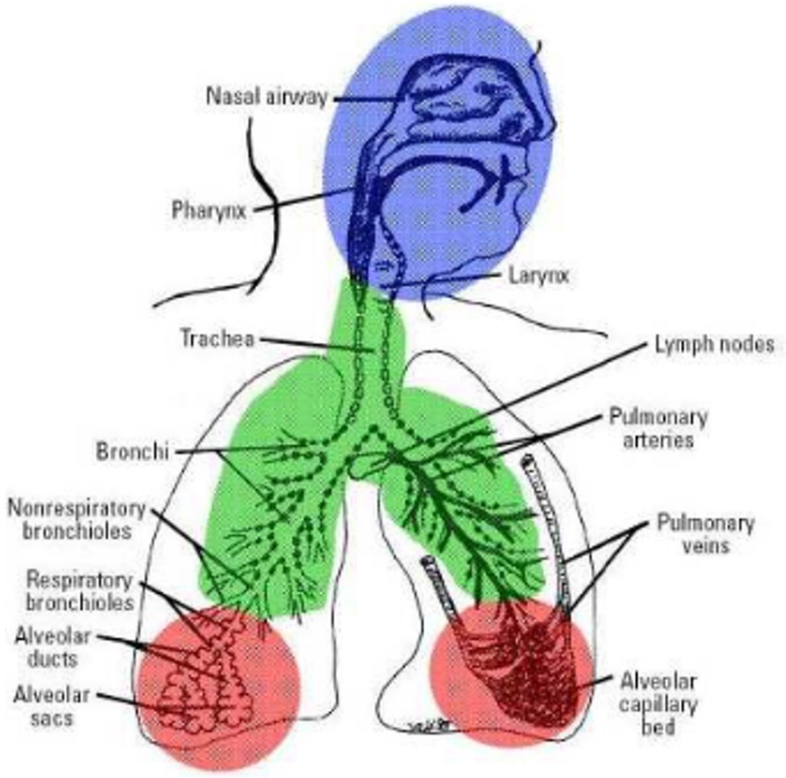


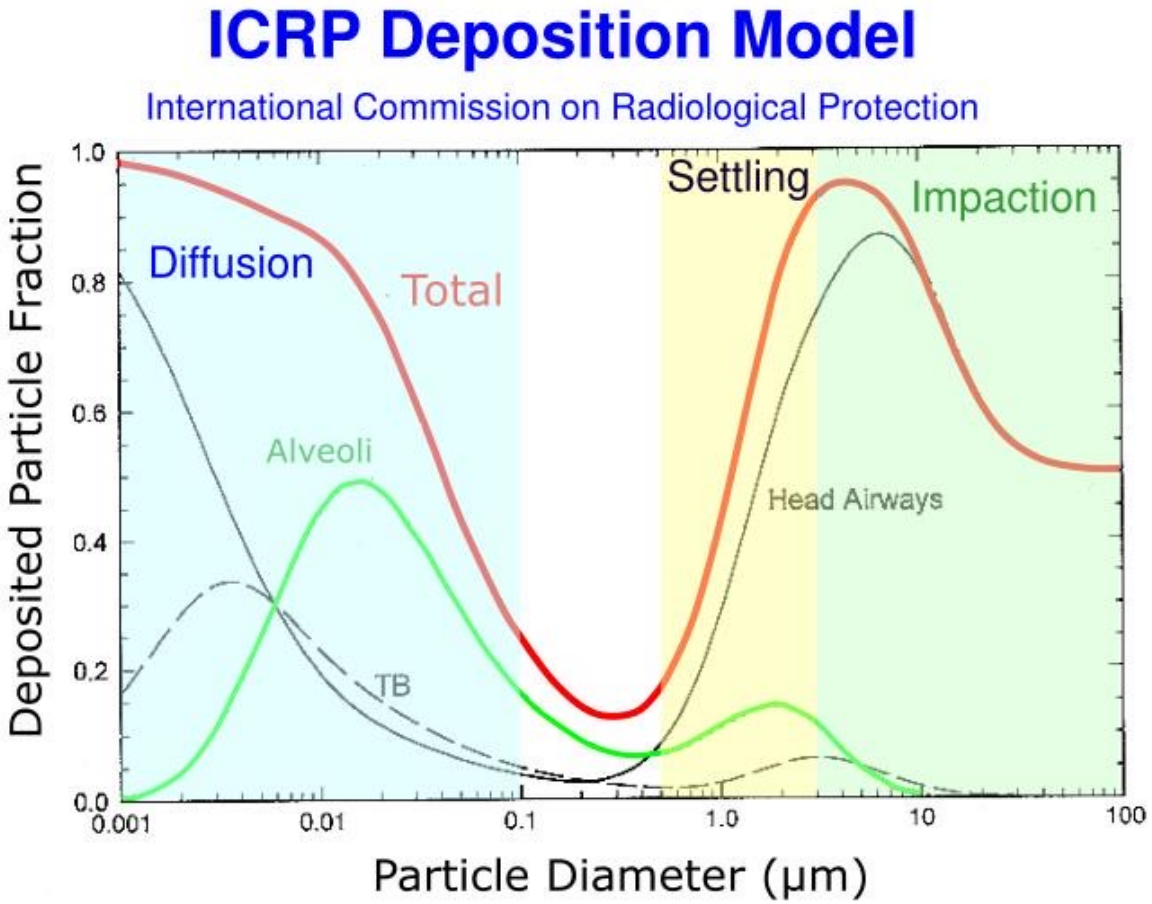


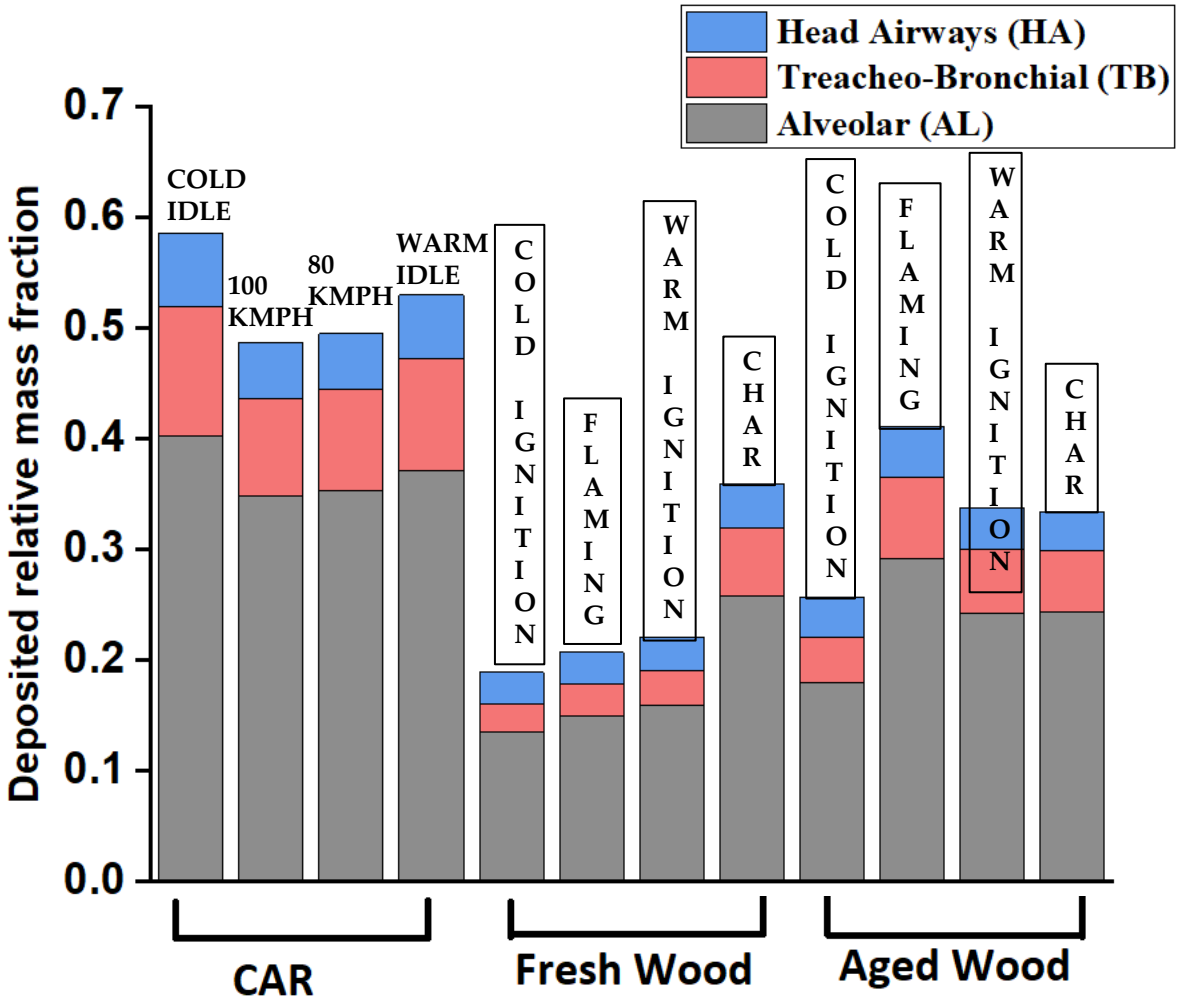


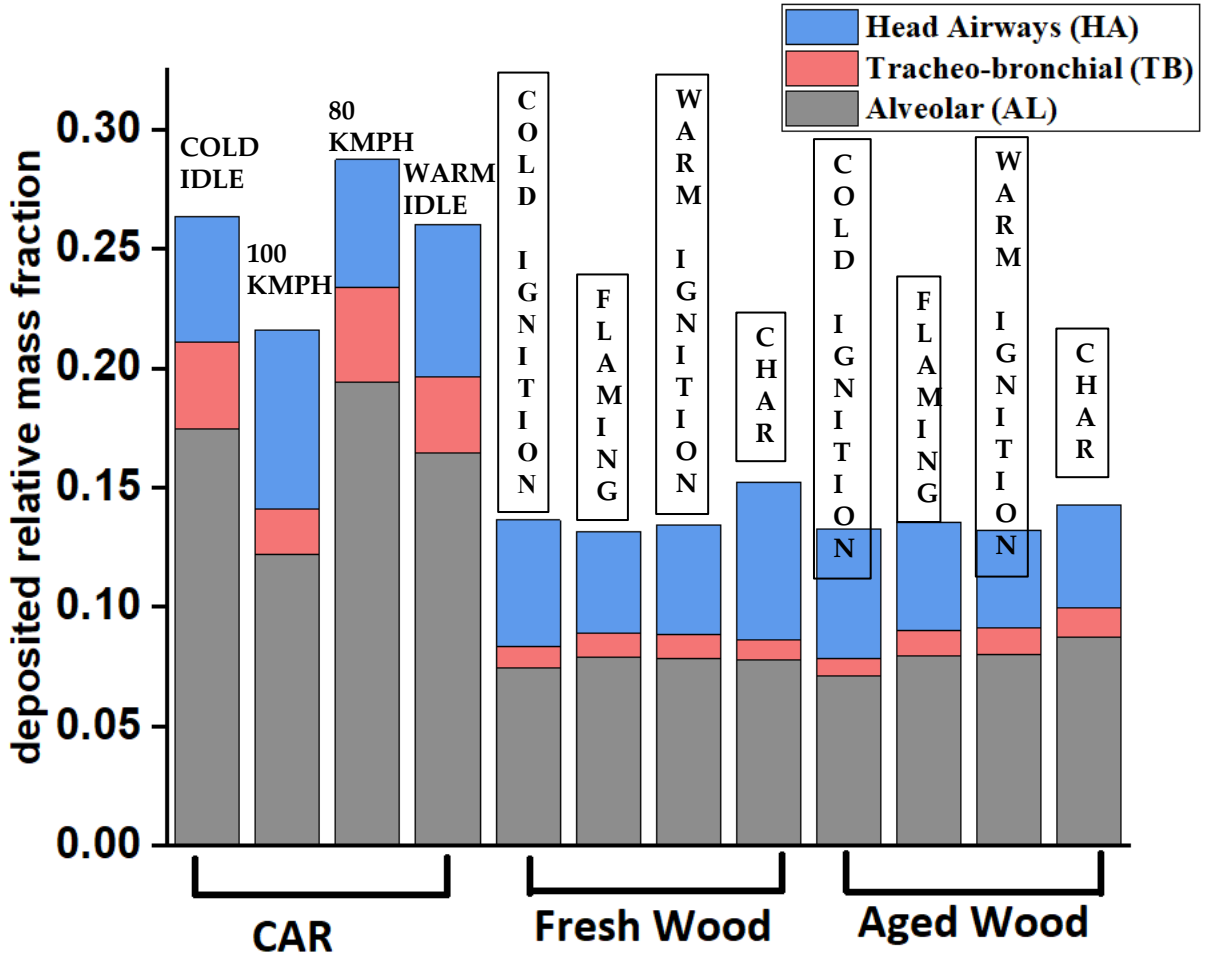





Nasal airway
Pharynx
Larynx
Trachea
Lymph nodes
Pulmonary arteries
Bronchi
Nonrespiratory bronchioles
Pulmonary veins
Respiratory bronchioles
Alveolar ducts
Alveolar sacs
Alveolar capillary bed


ICRP Deposition Model
International Commission on Radiological Protection
Deposited Particle Fraction
Particle Diameter (μm)
Diffusion
Total
Settling
Impaction
Alveoli
Head Airways
TB
1.0
0.8
0.6
0.4
0.2
0.0
0.001
0.01
0.1
1.0
10
100


Head Airways (HA)
Treacheo-Bronchial (TB)
Alveolar (AL)
Deposited relative mass fraction
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
COLD IDLE
100 KMPH
80 KMPH
WARM IDLE
COLD IGNITION
FLAMING
WARM IGNITION
CHAR
COLD IGNITION
FLAMING
WARM IGNITION
CHAR
CAR
Fresh Wood
Aged Wood


Head Airways (HA)
Tracheo-bronchial (TB)
Alveolar (AL)
deposited relative mass fraction
0.30
0.25
0.20
0.15
0.10
0.05
0.00
COLD IDLE
100 KMPH
80 KMPH
WARM IDLE
COLD IGNITION
FLAMING
WARM IGNITION
CHAR
COLD IGNITION
FLAMING
WARM IGNITION
CHAR
CAR
Fresh Wood
Aged Wood

Thank you!

Acknowledgements

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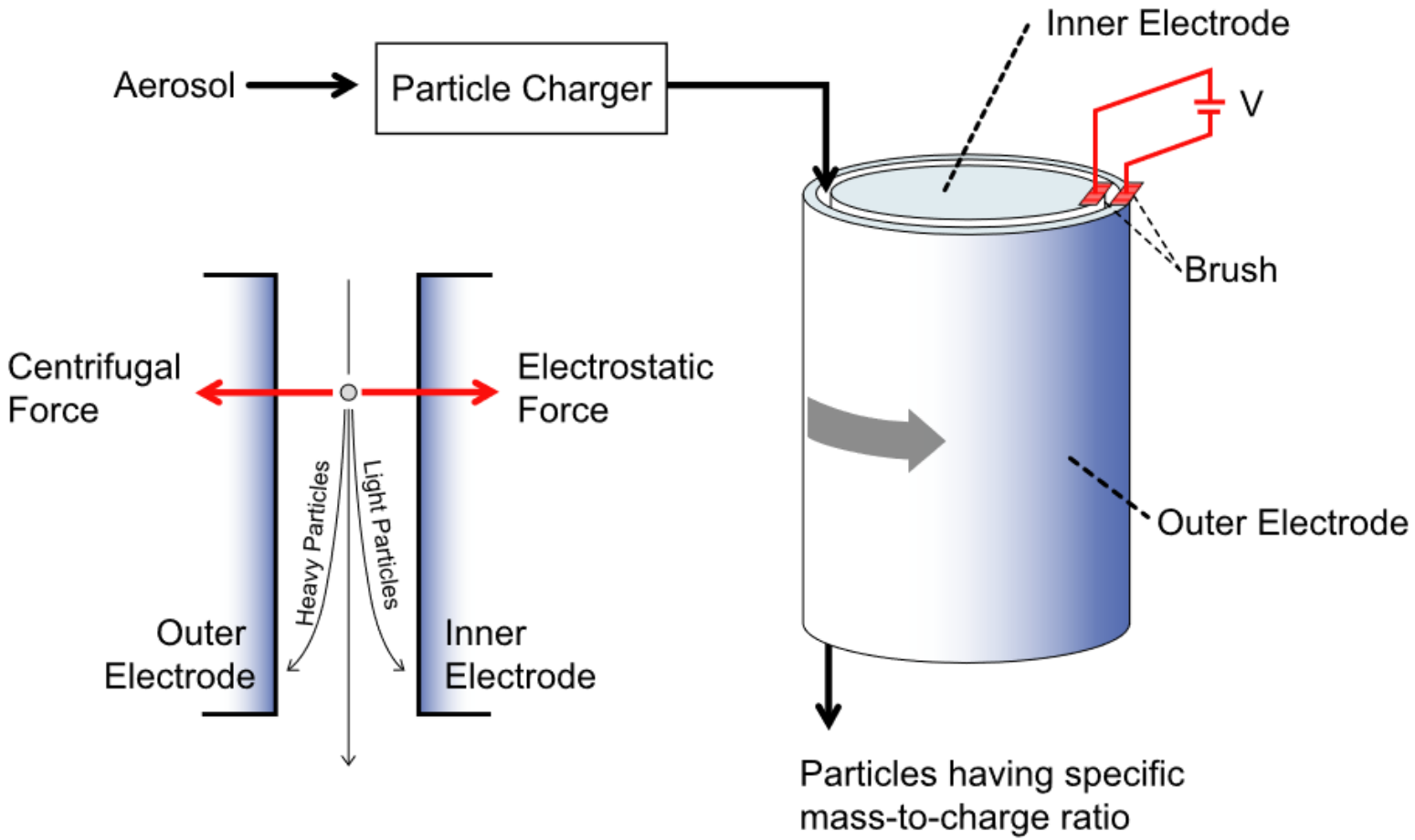
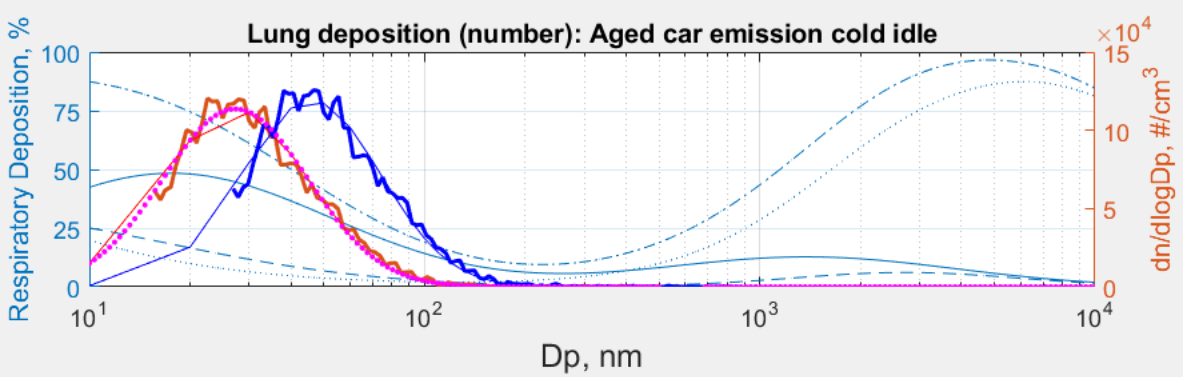
Additional slides

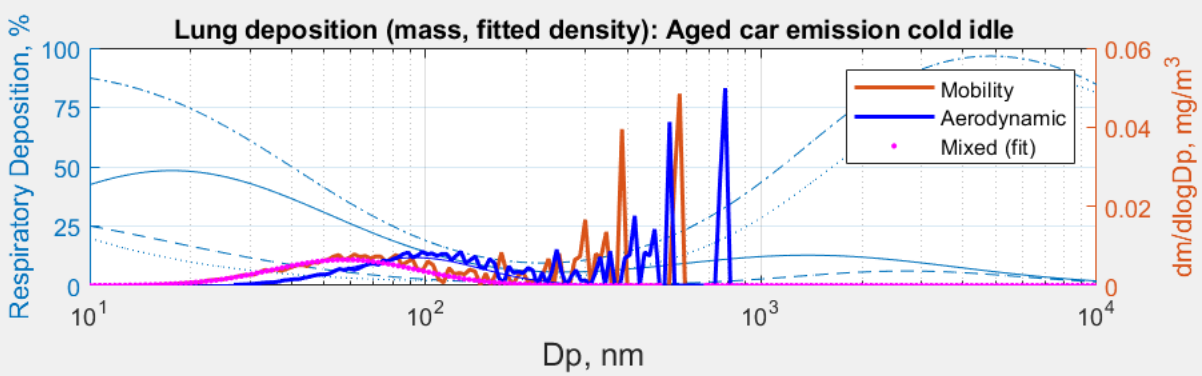
Methods

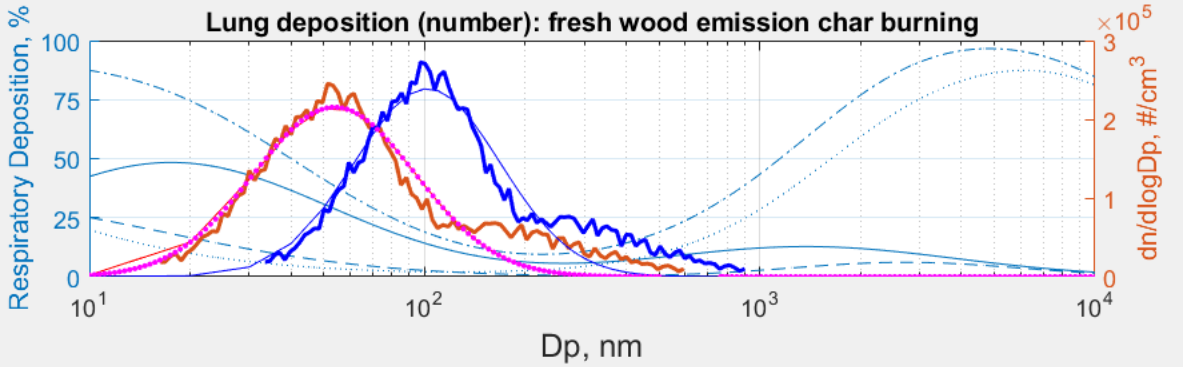
-Operation principle of APM

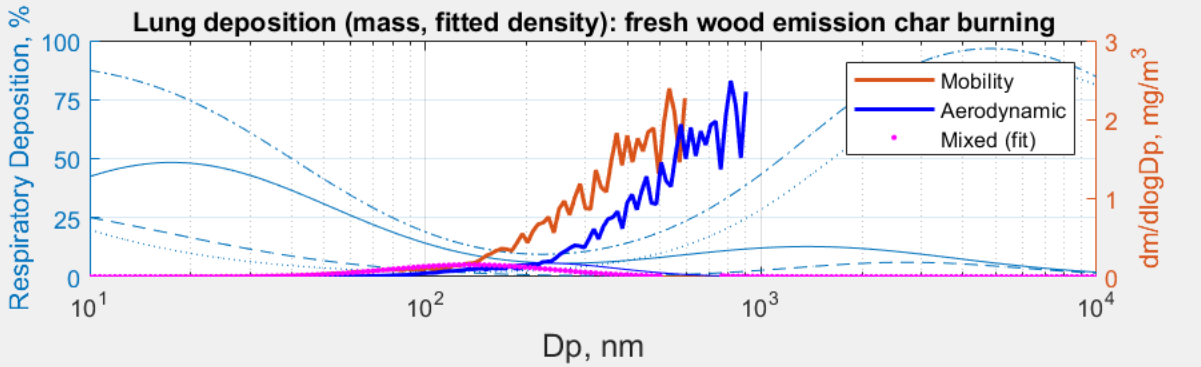
Classifies particles according to m/q

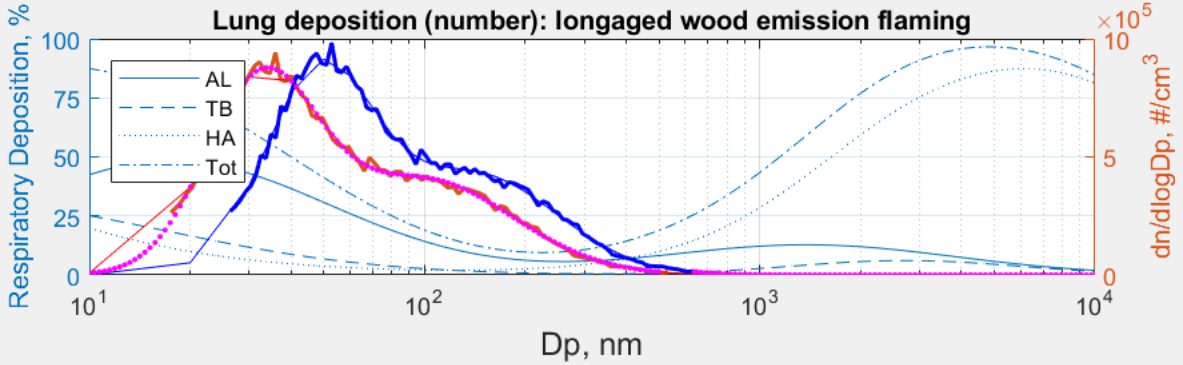


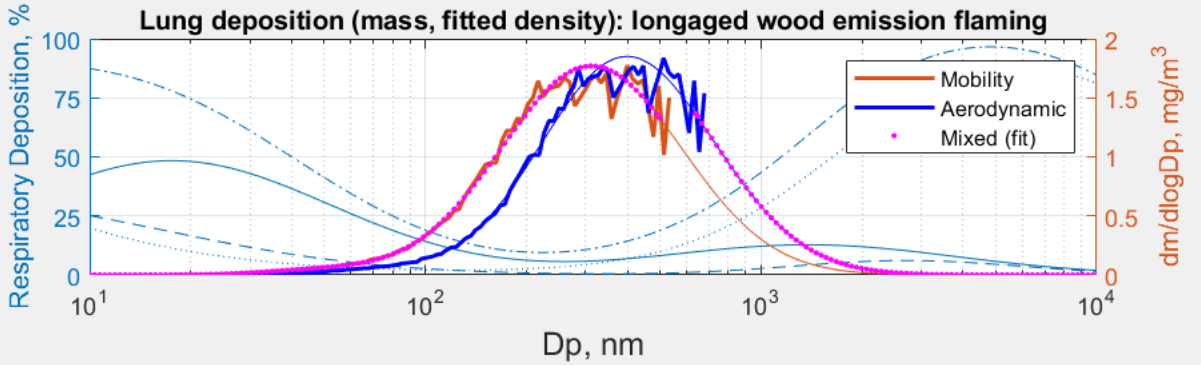

Lung deposition (number): Aged car emission cold idle
Respiratory Deposition, %
dn/dlogDp, #/cm3
Dp, nm

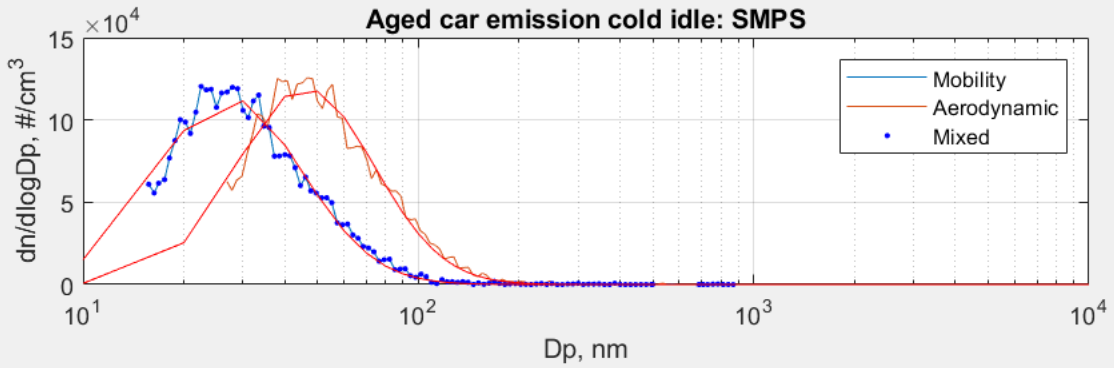

Lung deposition (mass, fitted density): Aged car emission cold idle
Respiratory Deposition, %
dm/dlogDp, mg/m3
Mobility
Aerodynamic
Mixed (fit)
Dp, nm

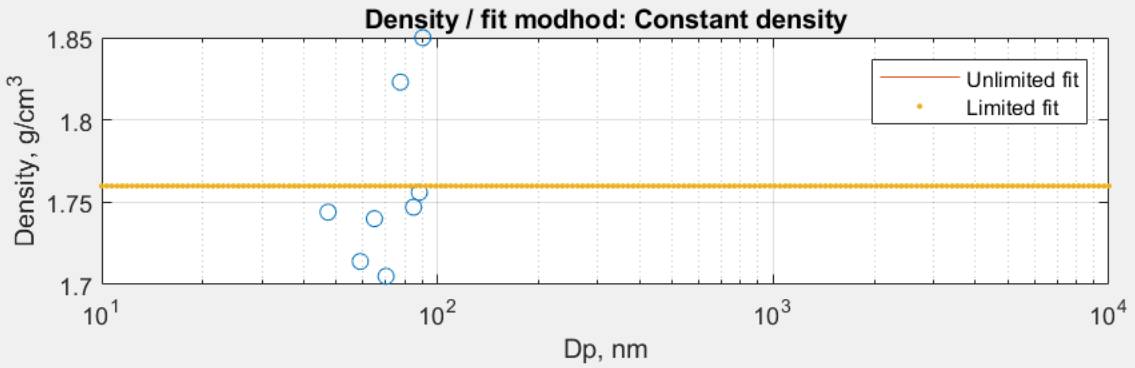

Lung deposition (number): fresh wood emission char burning
Respiratory Deposition, %
dn/dlogDp, #/cm3
Dp, nm

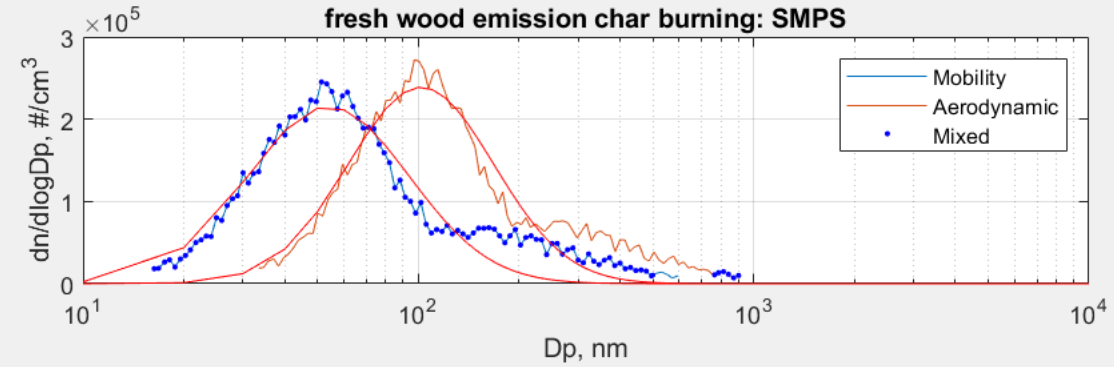

Lung deposition (mass, fitted density): fresh wood emission char burning
Respiratory Deposition, %
dm/dlogDp, mg/m3
Mobility
Aerodynamic
Mixed (fit)
Dp, nm

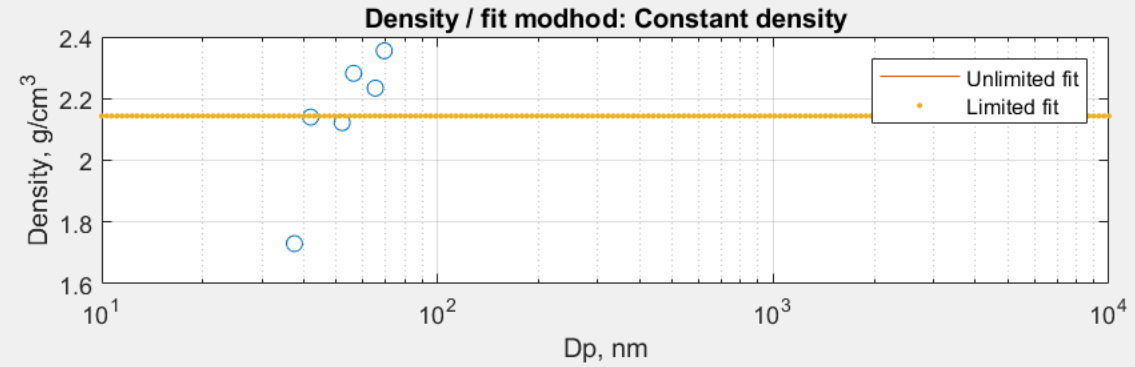

Lung deposition (number): longaged wood emission flaming
Respiratory Deposition, %
dn/dlogDp, #/cm3
AL
TB
HA
Tot
Dp, nm

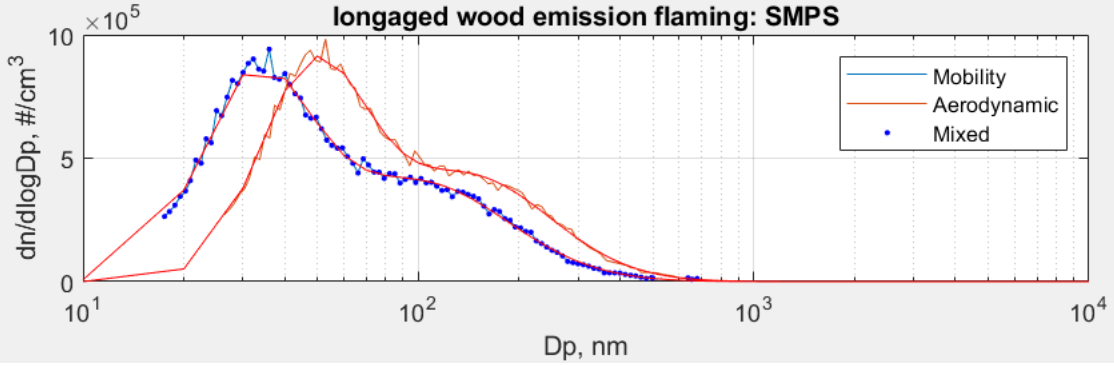

Lung deposition (mass, fitted density): longaged wood emission flaming
Respiratory Deposition, %
dm/dlogDp, mg/m3
Mobility
Aerodynamic
Mixed (fit)
Dp, nm

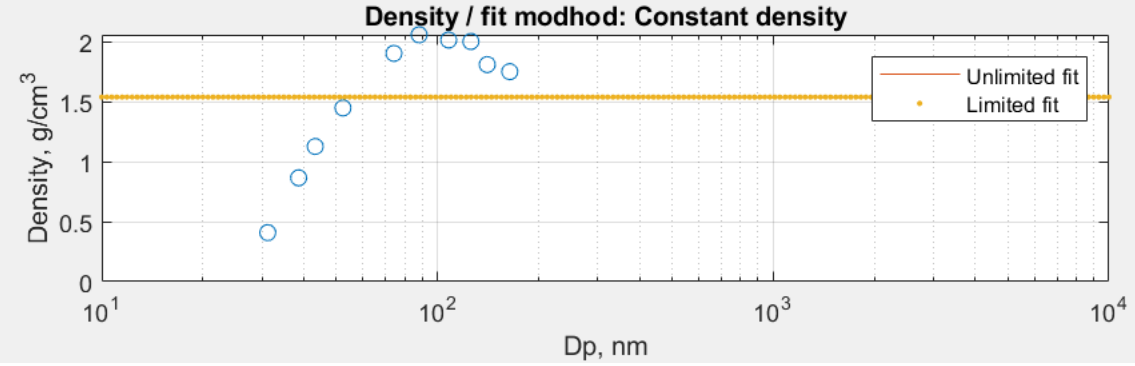

Aged car emission cold idle: SMPS
×10^4
dn/dlogDp, #/cm^3
Dp, nm
Mobility
Aerodynamic
Mixed

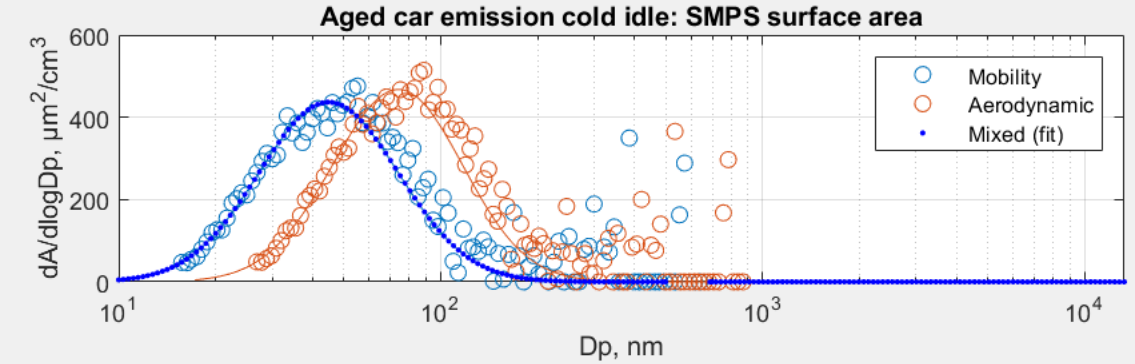

Density / fit modhod: Constant density
Density, g/cm^3
Dp, nm
Unlimited fit
Limited fit

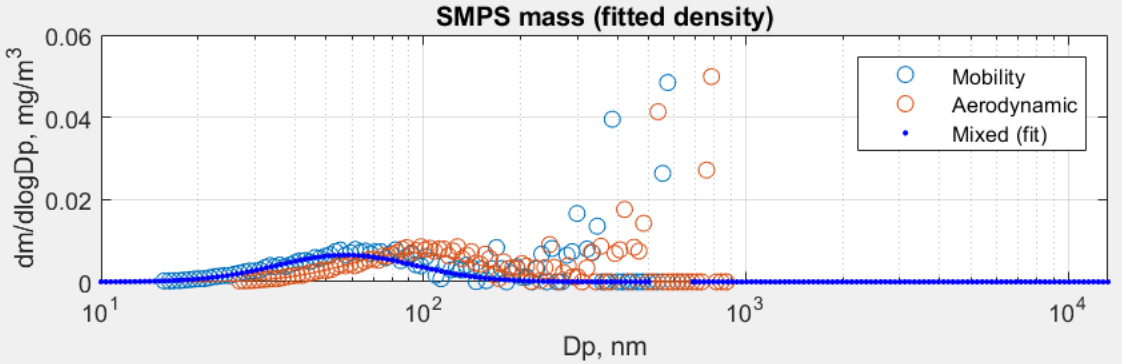

fresh wood emission char burning: SMPS
×10^5
dn/dlogDp, #/cm^3
Dp, nm
Mobility
Aerodynamic
Mixed

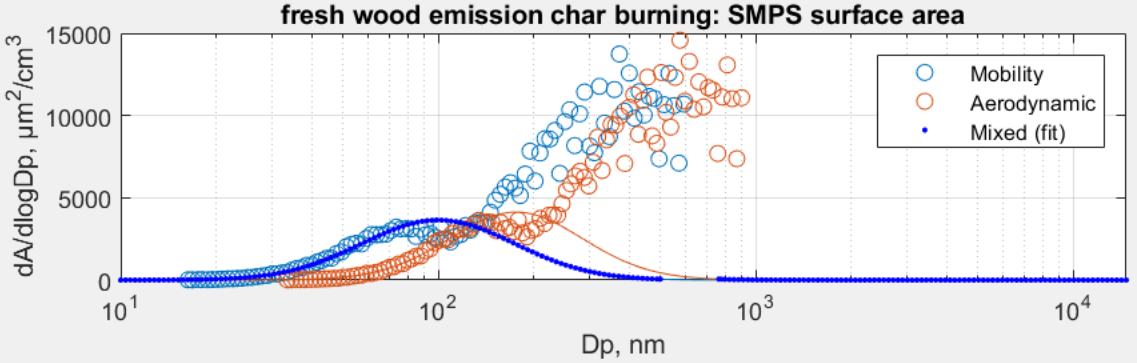

Density / fit modhod: Constant density
Density, g/cm^3
Dp, nm
Unlimited fit
Limited fit

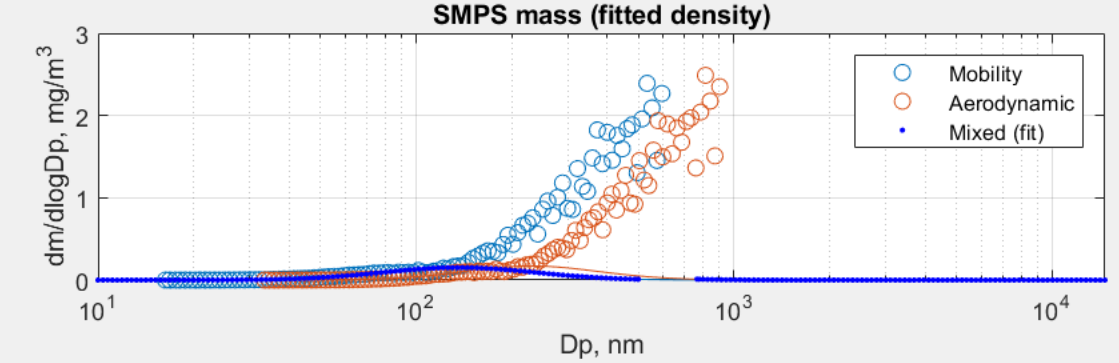

longaged wood emission flaming: SMPS
×10^5
dn/dlogDp, #/cm^3
Dp, nm
Mobility
Aerodynamic
Mixed

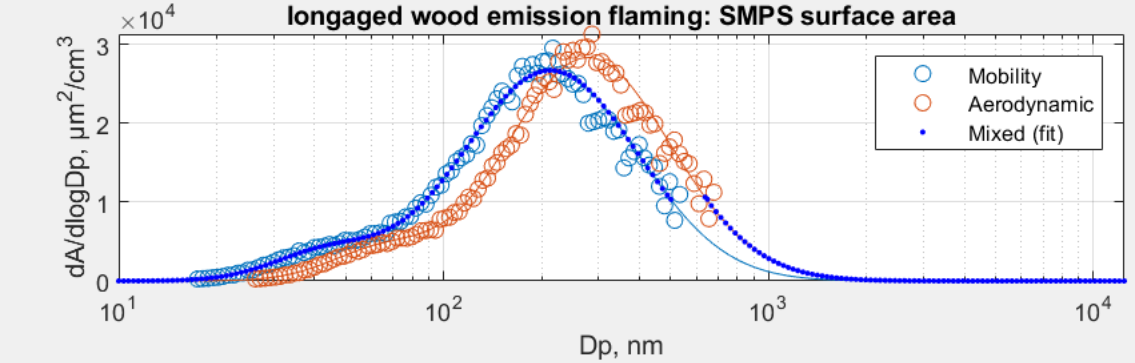

Density / fit modhod: Constant density
Density, g/cm^3
Dp, nm
Unlimited fit
Limited fit

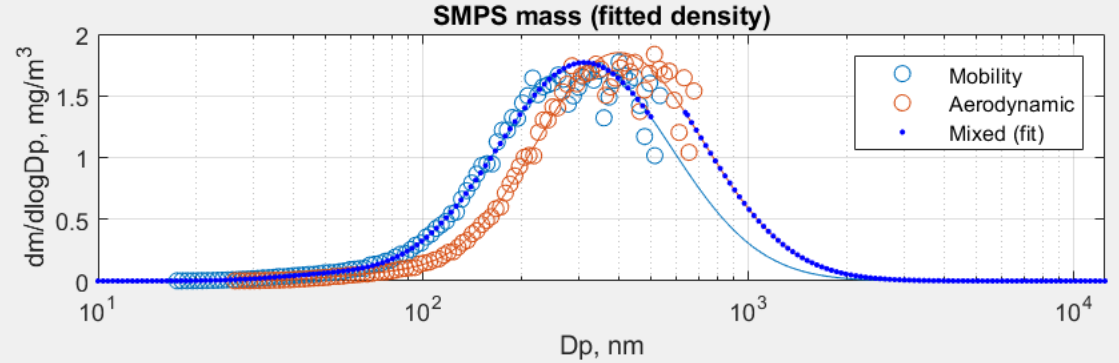

Aged car emission cold idle: SMPS surface area
dA/dlogDp, µm²/cm³
Dp, nm
Mobility
Aerodynamic
Mixed (fit)


SMPS mass (fitted density)
dm/dlogDp, mg/m³
Dp, nm
Mobility
Aerodynamic
Mixed (fit)


fresh wood emission char burning: SMPS surface area
dA/dlogDp, µm²/cm³
Dp, nm
Mobility
Aerodynamic
Mixed (fit)


SMPS mass (fitted density)
dm/dlogDp, mg/m³
Dp, nm
Mobility
Aerodynamic
Mixed (fit)


longaged wood emission flaming: SMPS surface area
×10⁴
dA/dlogDp, µm²/cm³
Dp, nm
Mobility
Aerodynamic
Mixed (fit)


SMPS mass (fitted density)
dm/dlogDp, mg/m³
Dp, nm
Mobility
Aerodynamic
Mixed (fit)