Modeling Aerosol Growth in Amine Scrubbing for Carbon Capture

PCCC4

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CCSI2 Carbon Capture Simulation for Industry Impact
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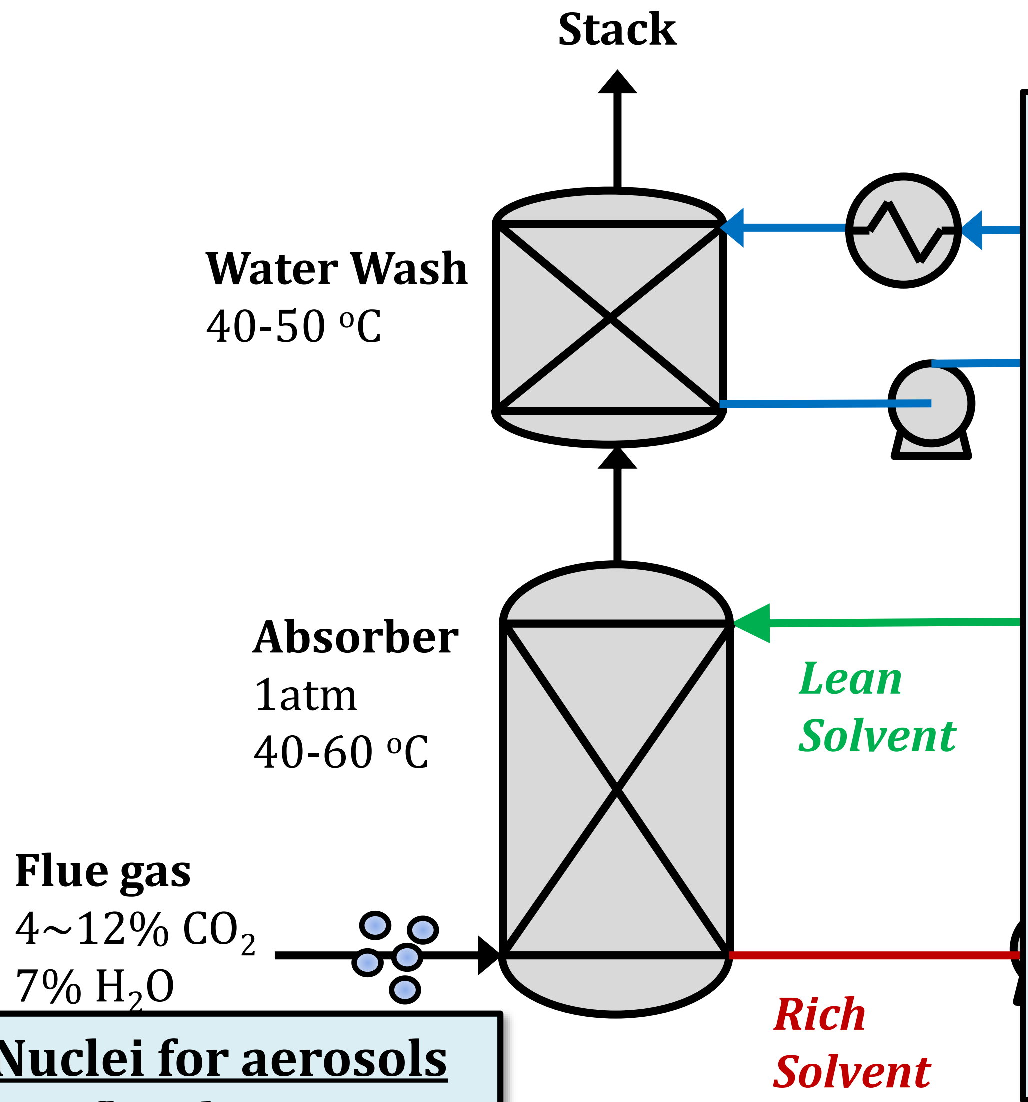
Amine Scrubbing Carbon Capture



Nuclei for aerosols

SO_x, fly ash

Bad

- **if aerosol is not captured: emissions result in solvent loss & environmental impact**

Good

- **if aerosol grows enough: will be captured. > 3 μm, captured by impaction**

This work

- **How much aerosol grows**
- **How we can manage aerosol growth**

PZ Makes Aerosol

- **April 2017 UT-SRP pilot plant with 5 m PZ and 52 ppm SO_3**

Growth Mechanisms Are NOT Well-understood

- **Limiting driving force for growth**
- **Solvent selection**
- **Operating conditions**

Sequential Aerosol Growth Model

PZ Model by *Fulk[1], Kang[2], and Zhang*

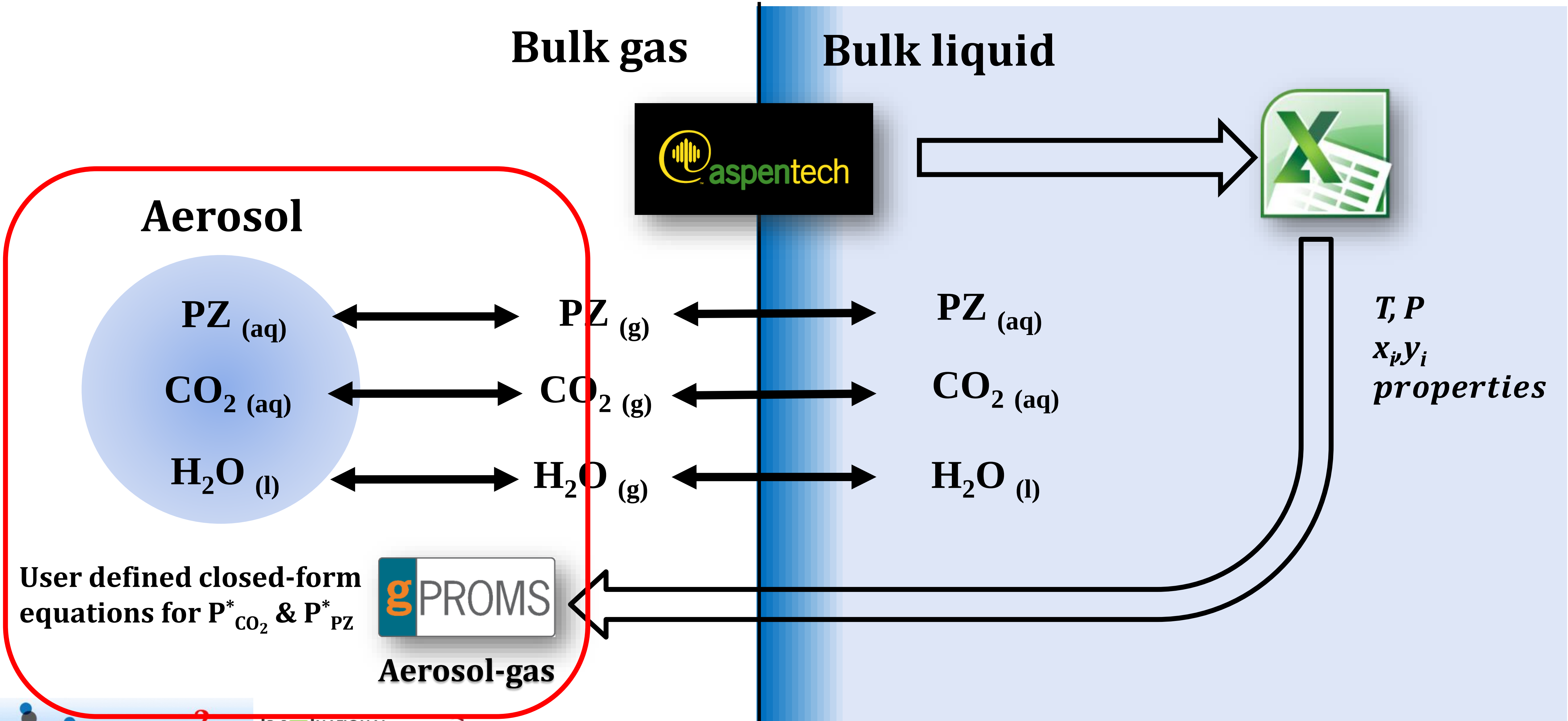
- **Steady-state absorber and water wash simulations in Aspen Plus, and aerosol calculations in gPROMS**
- **Proposed gas phase amine driving force depletion**

MEA Model by Majeed[3]

- **Steady-state absorber simulations in NTNU in-house simulator, and aerosol calculations in MATLAB**
- **Also proved gas phase MEA depletion**

Fulk, et al., 2016[1]
Kang, et al., 2017[2]
Majeed, et al, 2017[3]

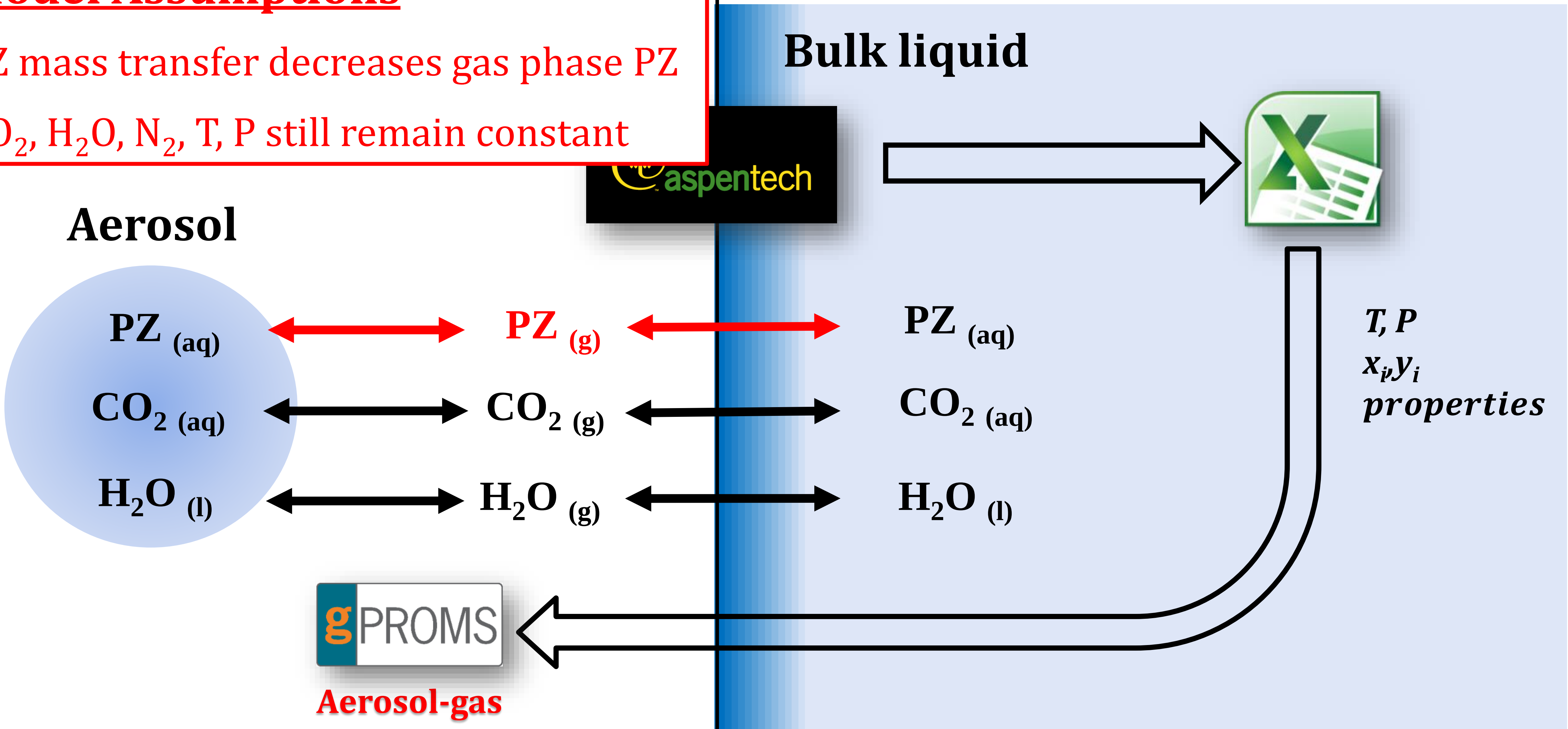
Sequential Aerosol Growth Model



Model Assumptions

PZ mass transfer decreases gas phase PZ

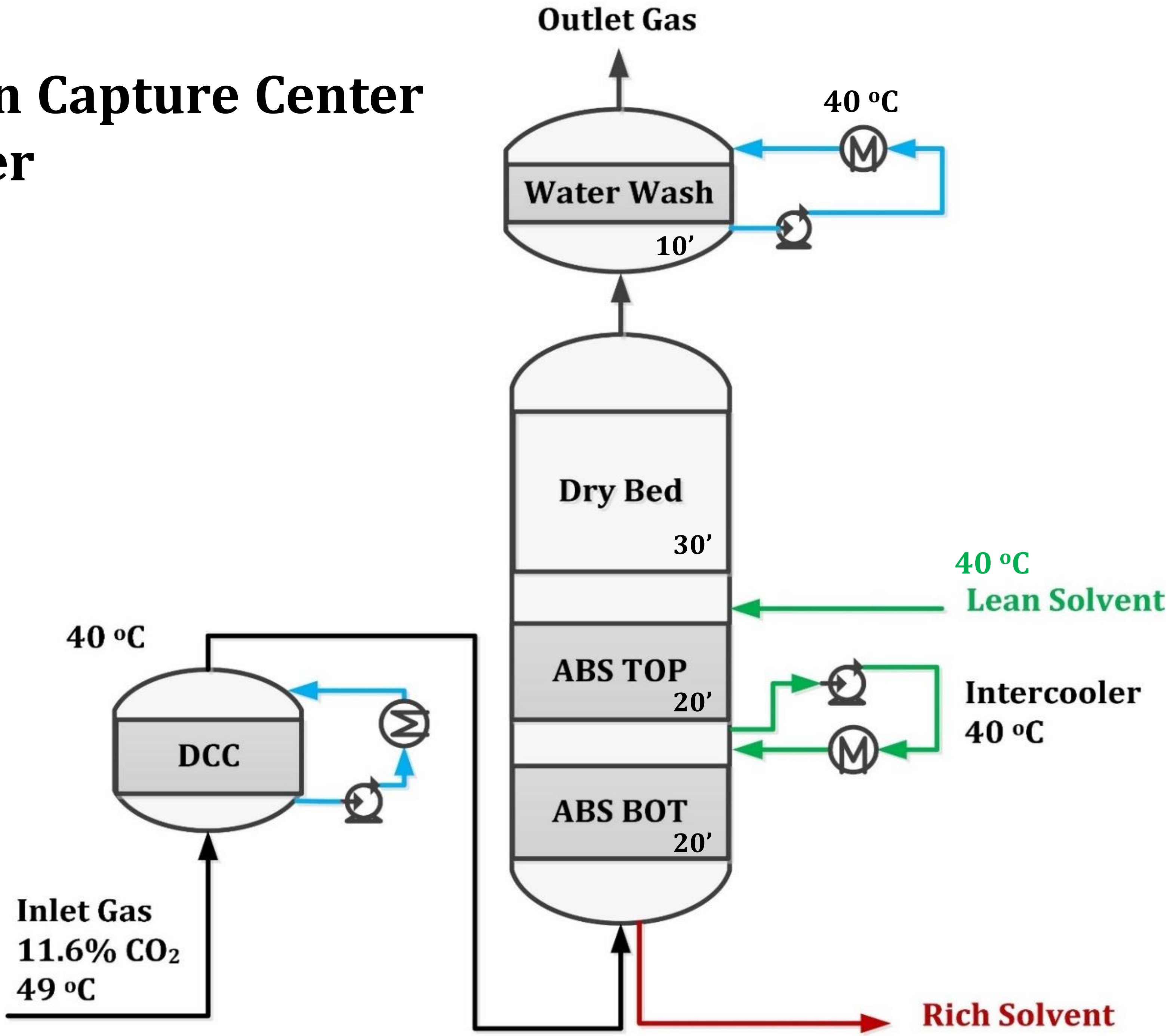
CO_2, H_2O, N_2, T, P still remain constant



Preliminary Modeling Results

Aerosol Growth at Realistic Plant Conditions

National Carbon Capture Center (NCCC) Absorber



Rate-based Absorber Modeling

PZ Independence Model

- Developed in Aspen Plus® RateSep™, with rigorous thermos and kinetics

Nov 2017 NCCC Campaign

- 0.5 MWe Pilot Solvent Test Unit , 90% removal
- 5 m PZ: fast absorption rate, low viscosity, good energy performance
- Lean Loading at 0.22 (mol CO_2/mol alk)

P. Frailie, 2014[1]

Assumptions for Aerosols

- **Well-mixed**
- **Particle conc at 10^7 part./cm^3**

  < 10^6 : emits < 1ppm amine

  > 10^8 : starts coagulation

  ~ 10^7 : most often observed at site

- **Initial conditions**

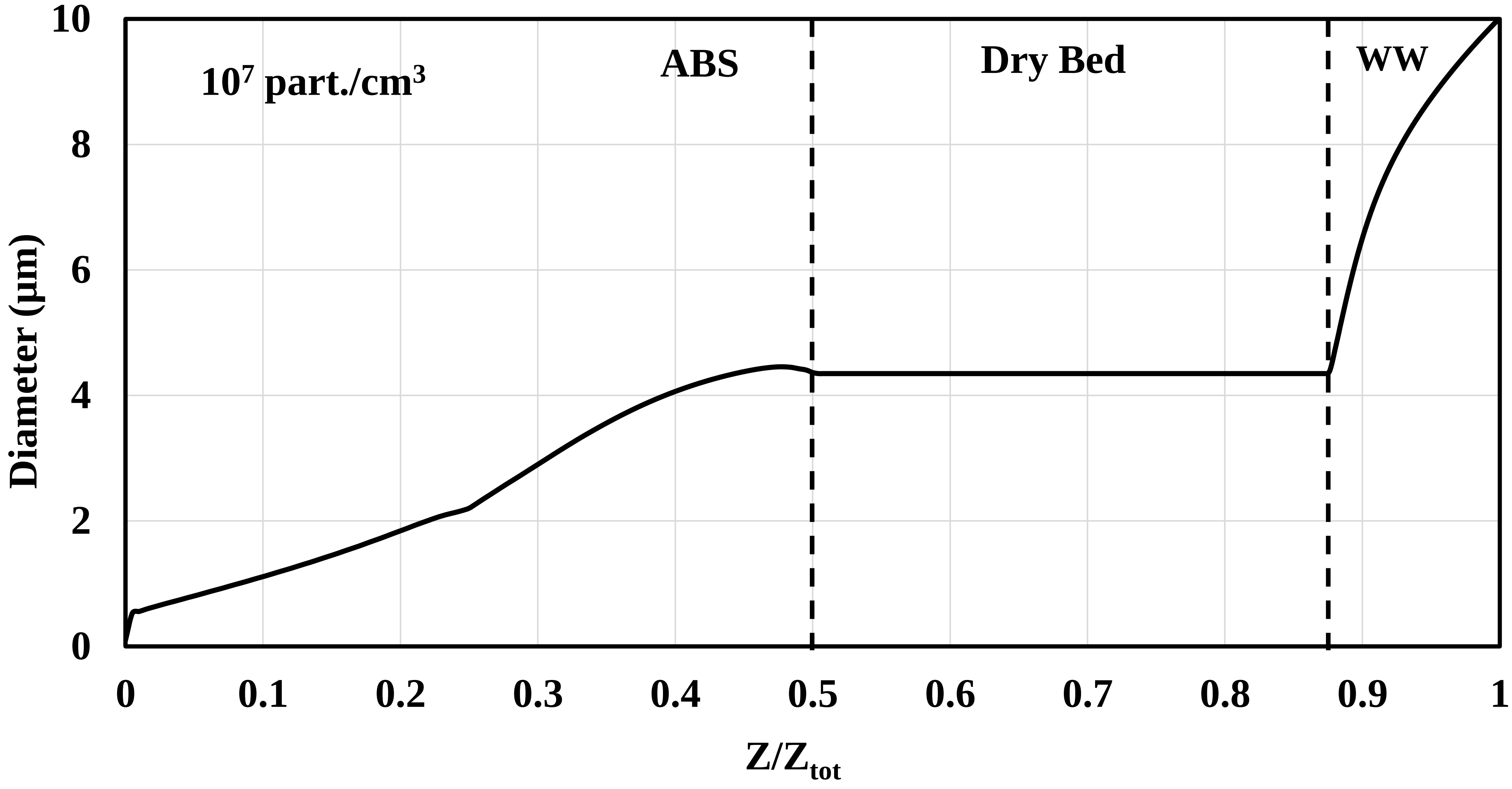
  0.1 µm, 5 m PZ, 0.36 CO_2 loading

$PZ_{(aq)}$

$CO_{2\,(aq)}$

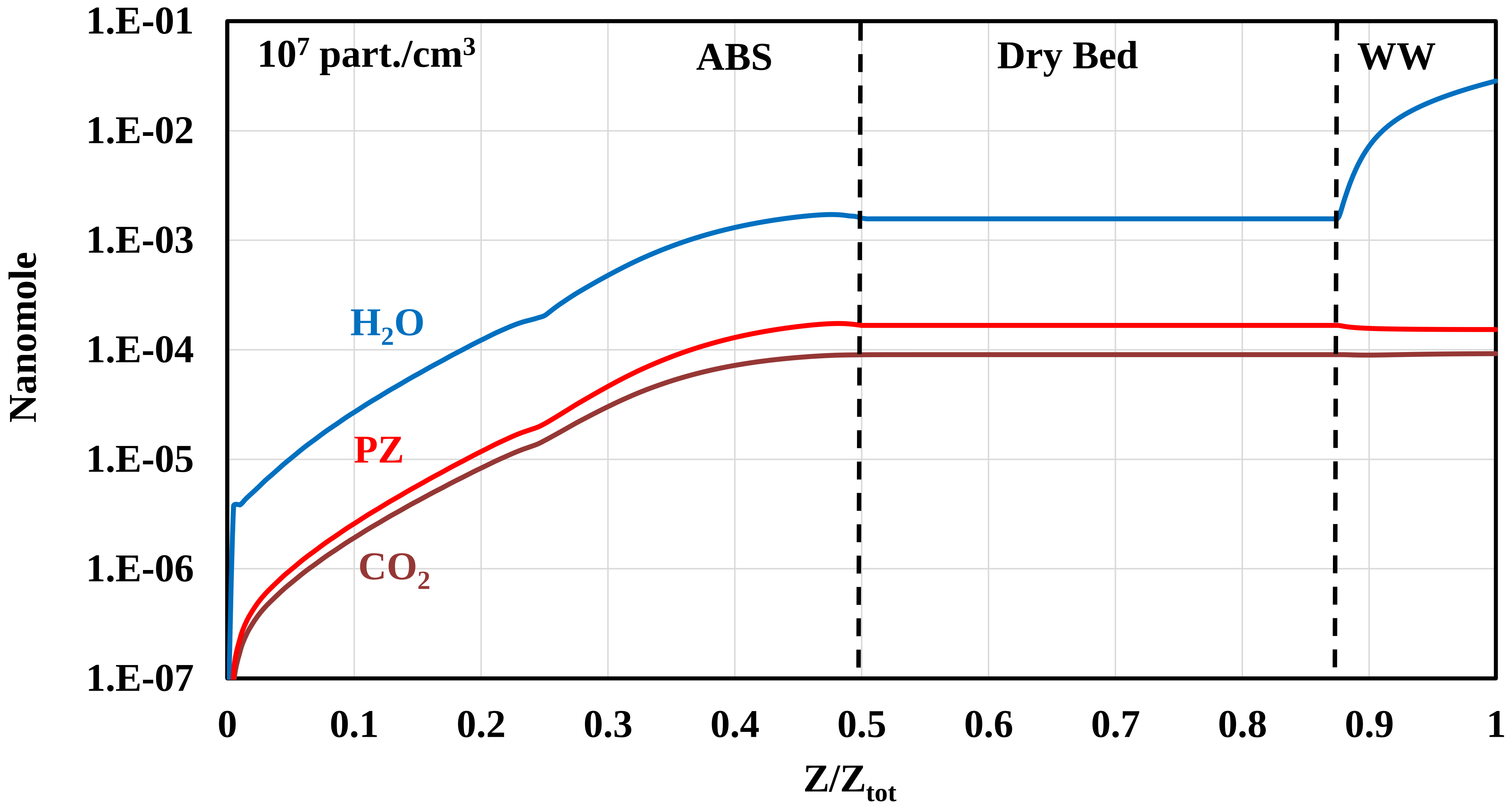
$H_2O_{(l)}$

General aerosol growth profile



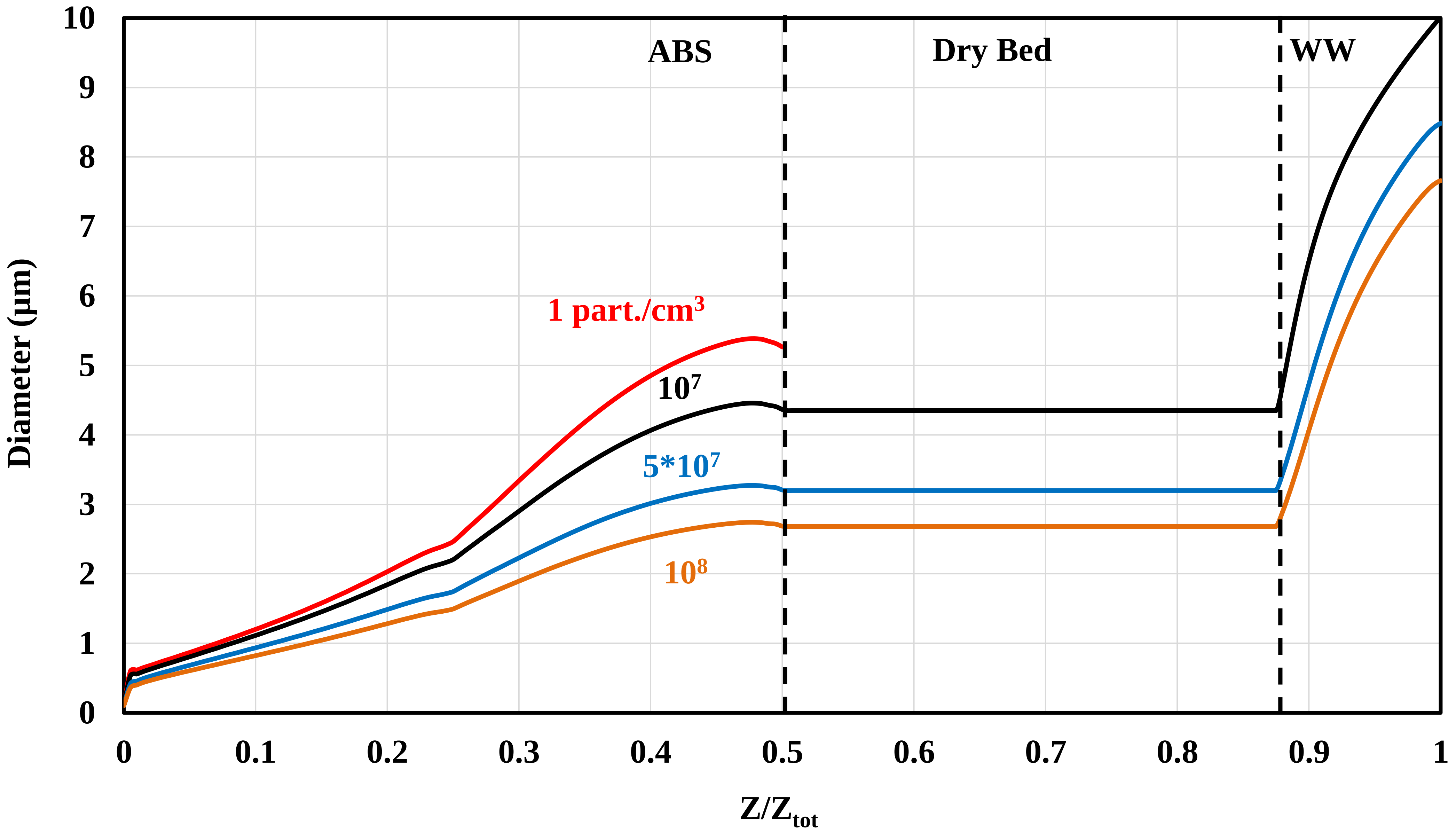
- **Aerosols grow from 0.1µm to 4.4 in ABS, and 10 in WW (collectable)**
- **Aerosol initial diameter is not critical**

Component pickup in aerosol

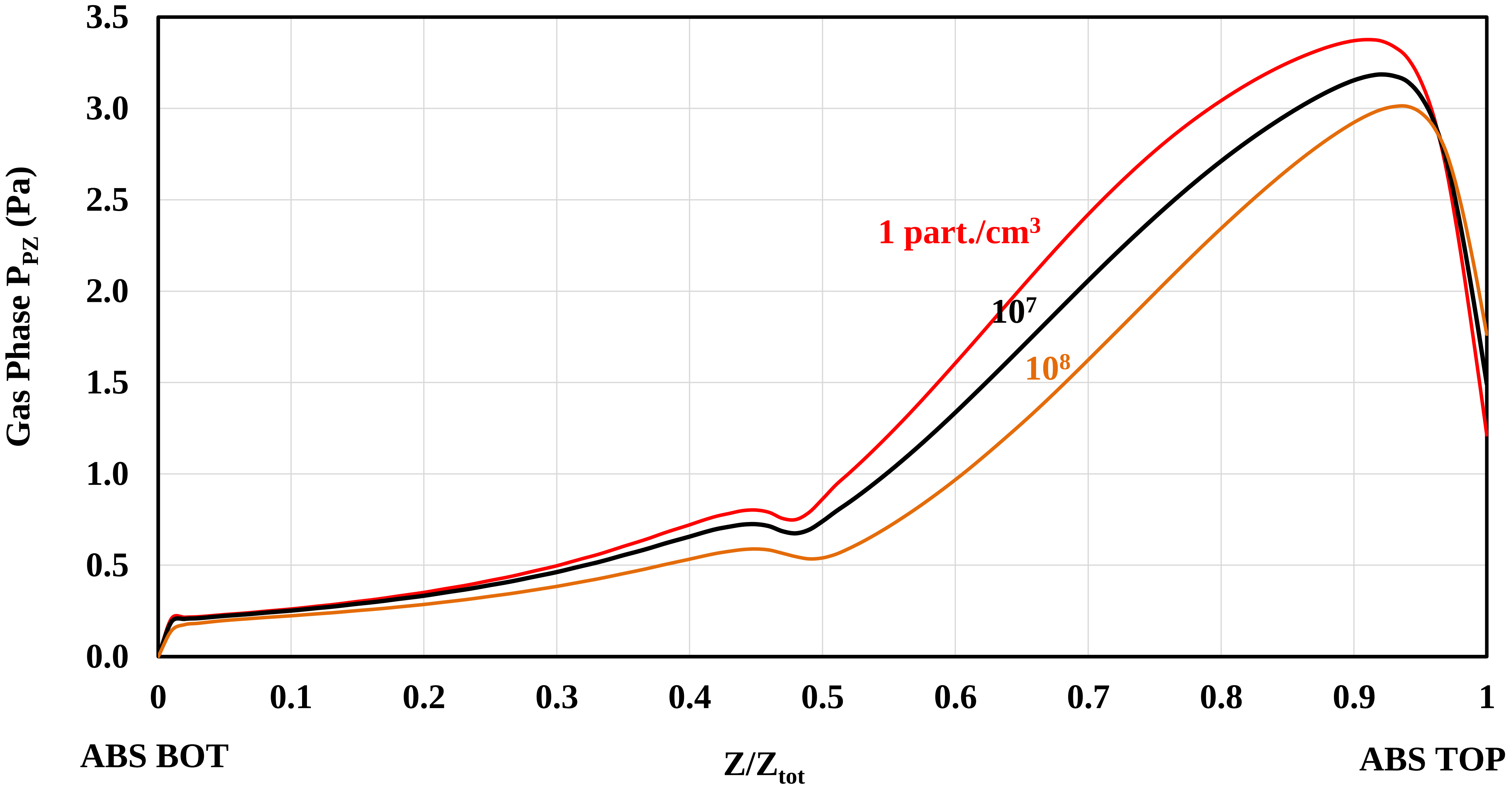


- **Aerosols grow in WW by picking up water**

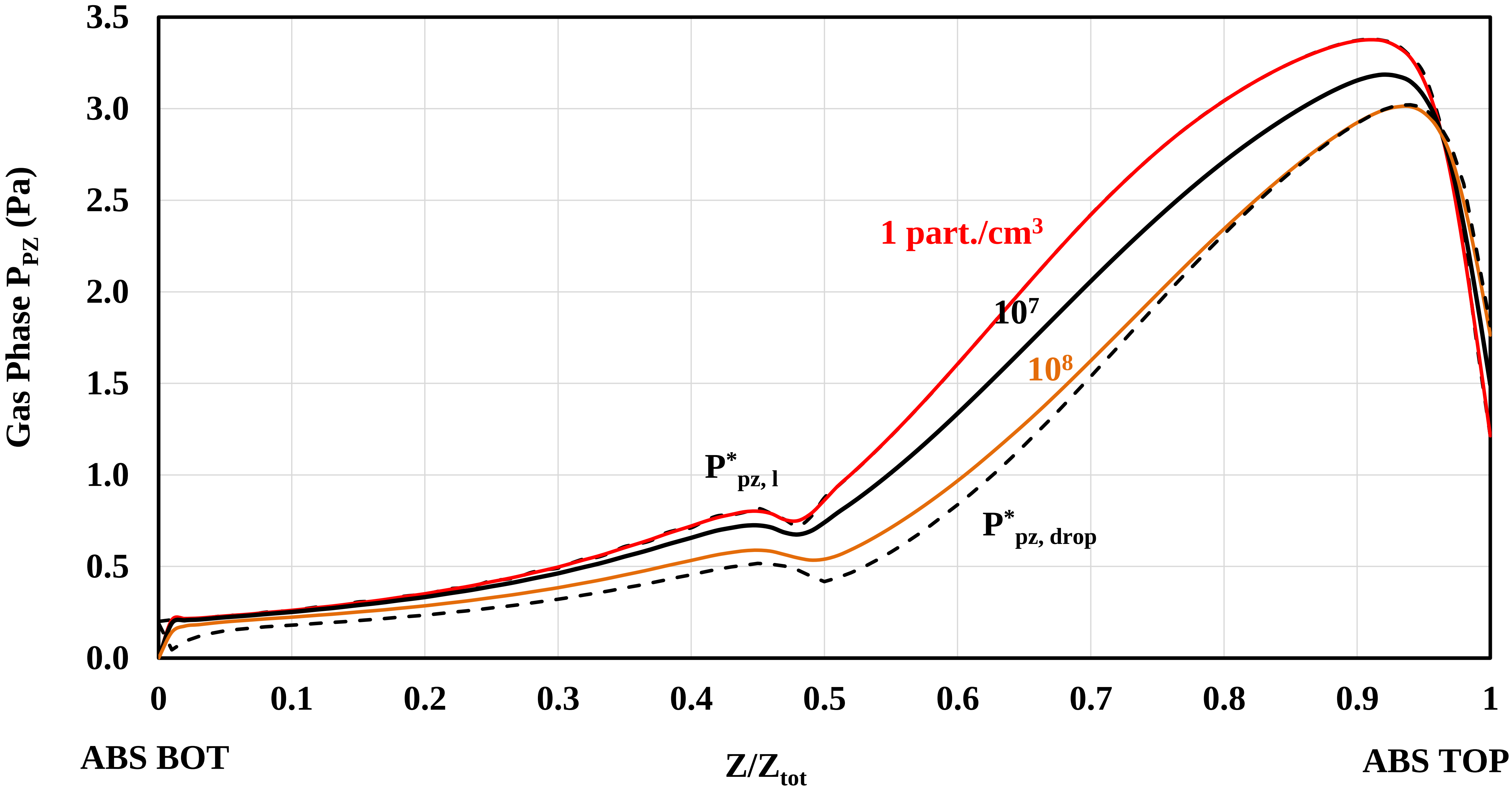
High part. conc reduces aerosol growth



PZ driving force depletion in gas phase

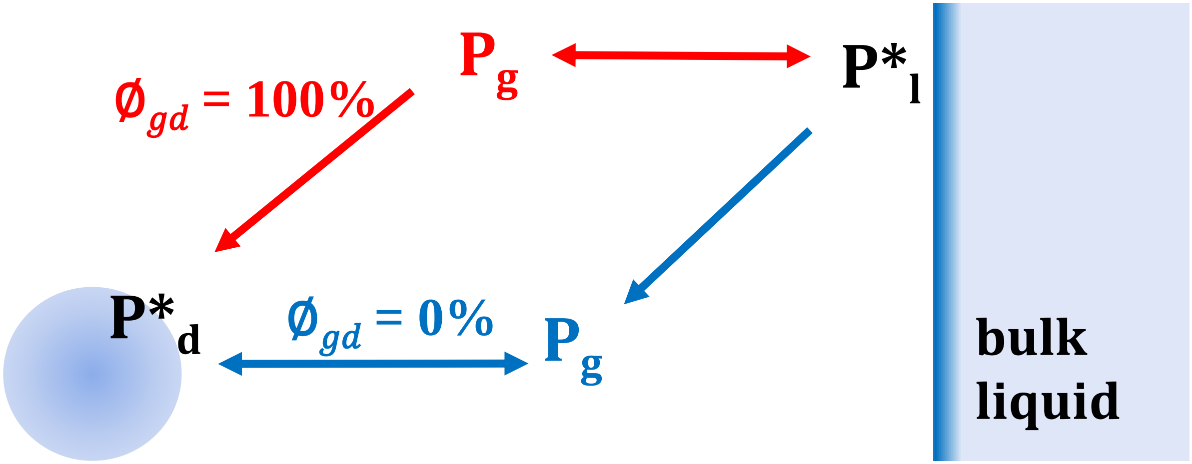


PZ driving force depletion in gas phase



Relative driving force ratio between g-d

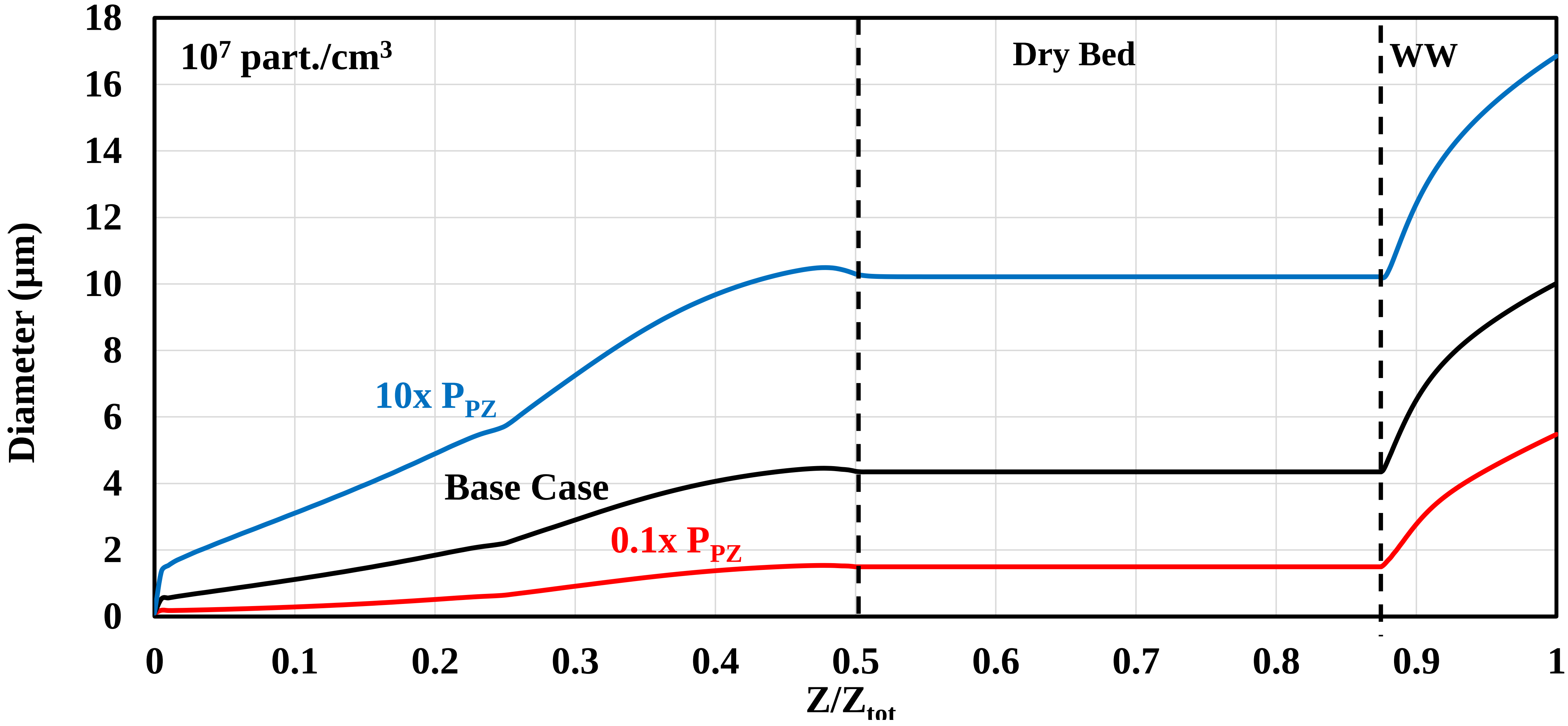
$$\varnothing_{gd} = \frac{\Delta P_{gd}}{\Delta P_{ld}}$$



	1 part./cm³	10^7	10^8
Avg $\varnothing_{gd,\ PZ}$	100%	72%	32%
Avg $\varnothing_{gd,\ water}$	0%	0%	0%

- **The limiting driving force of growth is PZ**
- **As part. conc increases, limiting driving force (PZ) shifts from g-d to l-g**
- **Aerosol is always in equilibrium with water in gas**

Increase and decrease PZ volatility by 10x



- **Choose solvents with moderate volatility, like PZ (collectable)**
- **Avoid solvents with low volatility (non-collectable)**

Conclusions - growth mechanisms

- **As part. conc increases, aerosol growth decreases due to amine driving force depletion. The limiting driving force shifts from g-d to l-g**
- **In NCCC with 5 m PZ**
  - **10^7 part./cm^3 are collectable**
  - **w/o water wash, 10^8 part./cm^3 are non-collectable**
- **Higher amine volatility increases growth**

Recommendations

- **Nuclei**
  - **Reduce aerosol nuclei below 10^6 part./cm^3**
- **Solvent selection**
  - **Choose solvents with moderate volatility, like PZ**
  - **Avoid solvents with low volatility**

For more information

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Supplemental Slides

Industrial Configurations for Emissions Control

Configurations demonstrated in field

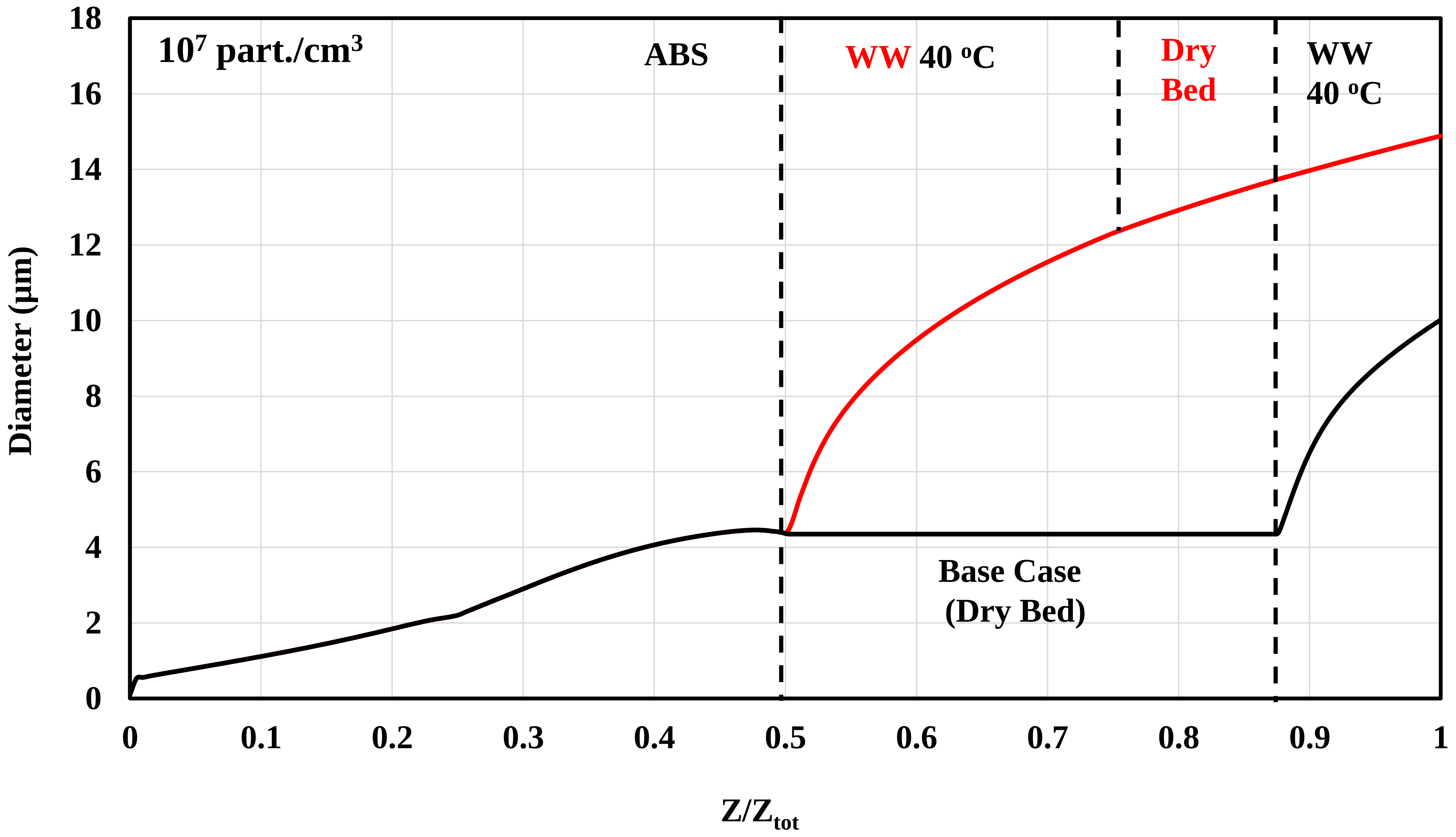
- **Acid Wash by *Aker Solutions*[1,2]**
- **Two-stage Water Wash by *Linde-BASF*[3]**
- **Dry Bed by *BASF-Linde-RWE Power*[4,5]**

In this study

- **Aerosol with a wide range of particle number conc**
- **Amine with different volatility**
- **Dry Bed, Intercoolers, Multi-stage Water Wash**

J. Knudsen, et al., 2013[1]
O. Bade, et al., 2014[2]
T. Stoffregen, et al., 2014[3]
P. Moser, et al., 2013[4]
P. Moser, et al., 2014[5]

Dry bed needs to be pre-humidified to grow aerosols



Possible Future Work

- Test a wide variety of amines/blends
- Particle size/residence time distribution