Reducing Ultra-High-Purity (UHP) Gas Consumption By Characterization of Trace Contaminant Kinetic and Transport Behavior in UHP Fab Environments

Customized Project; Sponsored by Intel

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PI:

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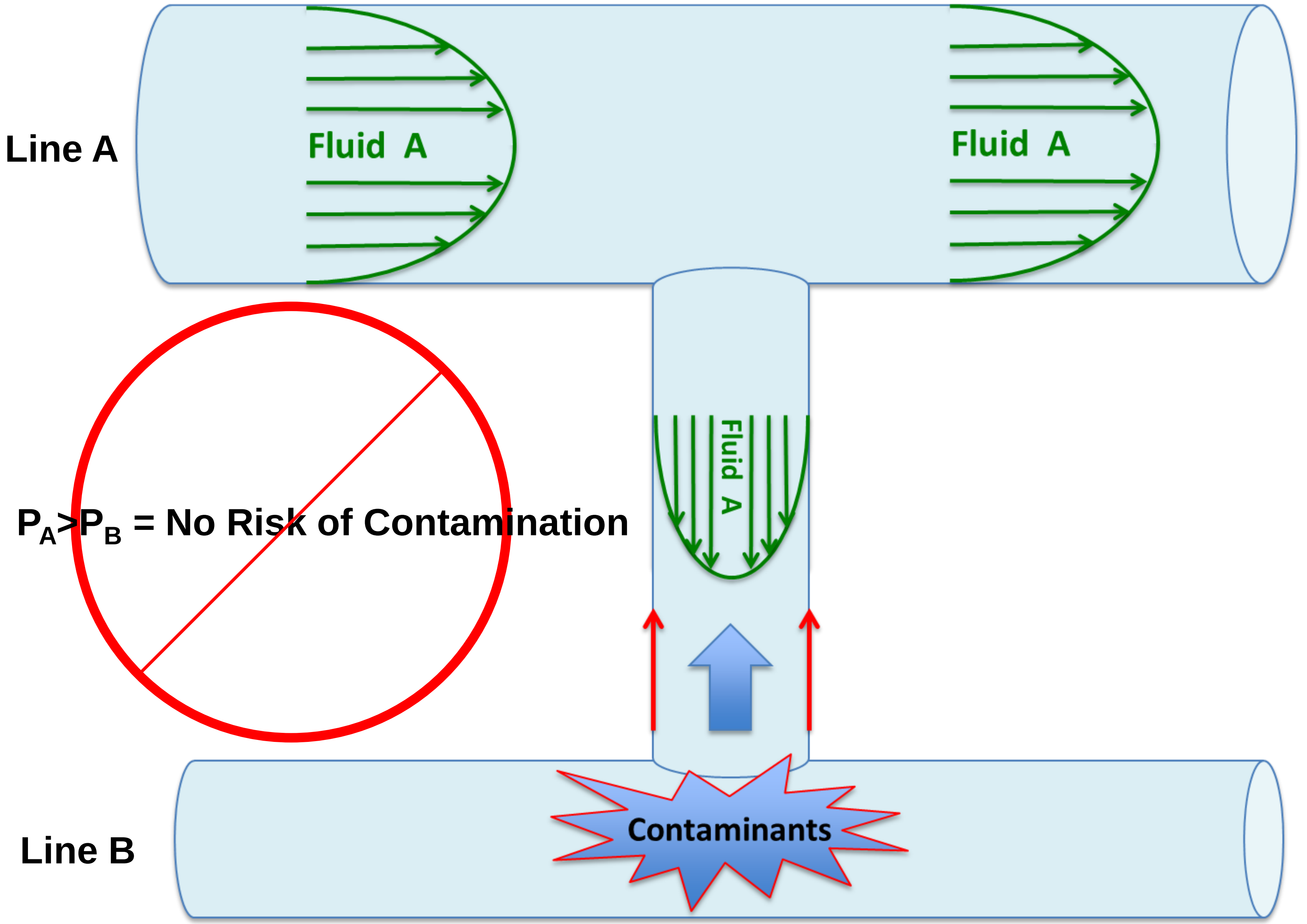
Co-PI:

- **Carl Geisert, Sr. Principal Engineer, Intel**

Back Diffusion Sources and Mechanisms



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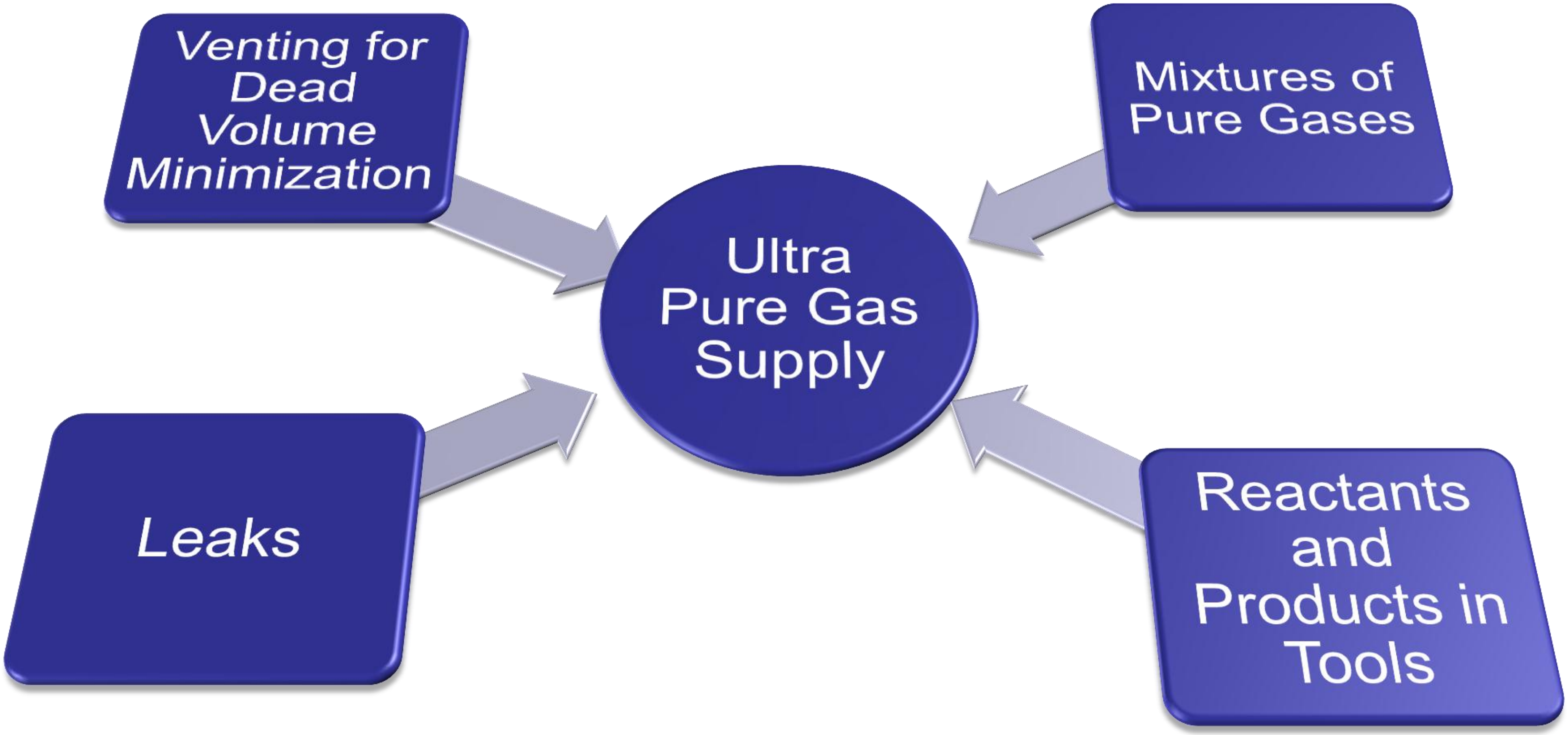


Objectives

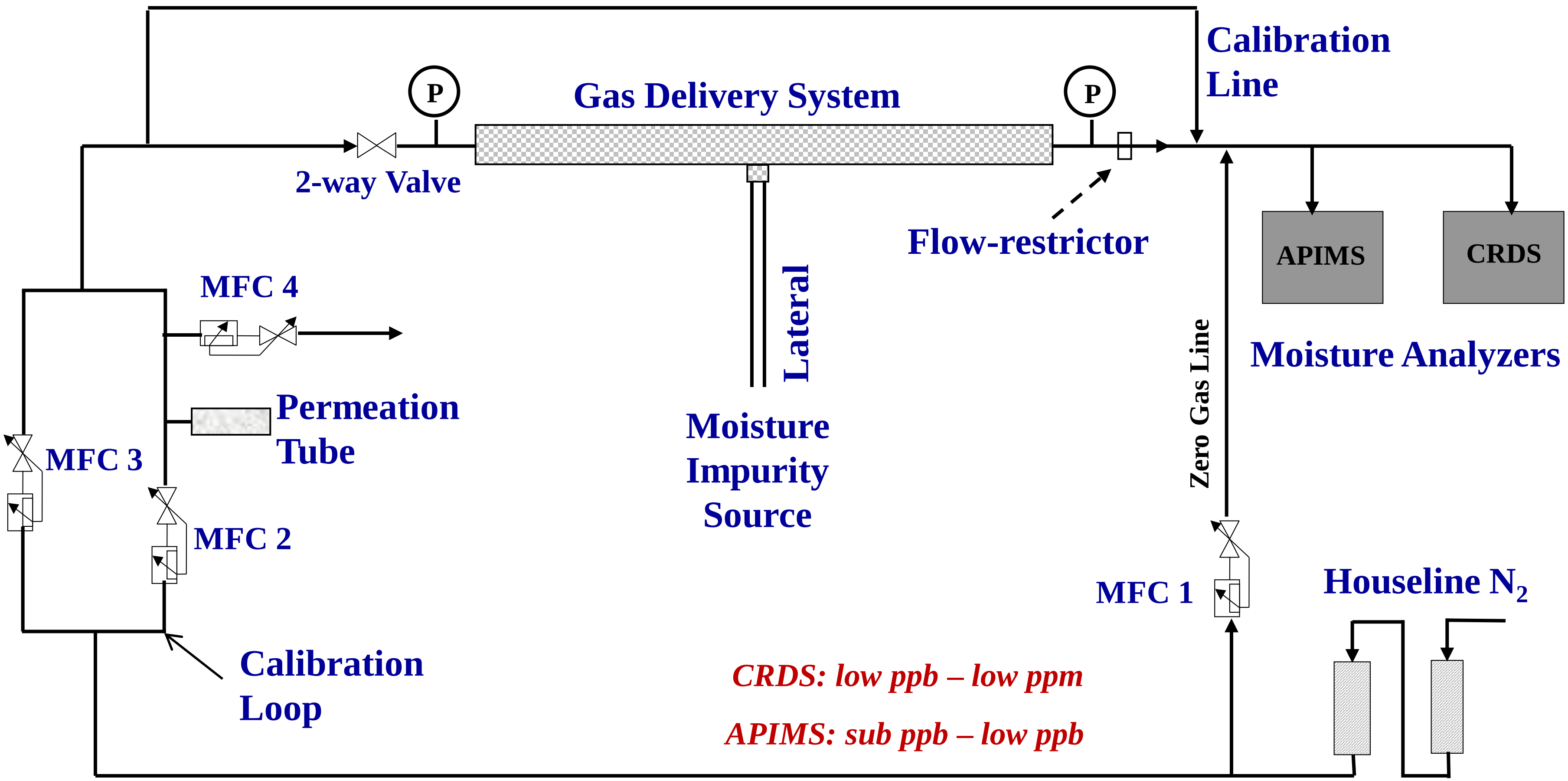
- Develop operational parameters that will minimize back diffusion of impurities into fluidic distribution systems.
- Develop and validate a process simulator that can help industry design and operate systems while minimizing back diffusion, gas usage, and system dead volumes.
- Develop a better understanding of back diffusion since little is known or has been published on the subject.

Motivation and ESH Impact

- Contamination of gas distribution systems during normal operation results in major wasting of materials, energy, and valuable tool operation time.

Experimental Testbed

Laterals Added to the Main Line



Gas distribution systems with different sizes and geometries were fabricated and provided by Intel

Back Diffusion Process Simulator

Convective Flux

$$J_c = -U_3 C_g$$

Gas Phase Dispersive Flux

$$J = -D\frac{dC_g}{dz}$$

Surface Diffusive Flux

$$J_s = -D_s\frac{dC_s}{dz} - D_s\frac{k_a}{k_d}\frac{dC_g}{dz}$$

Total Dispersive Mass Flow Rate

$$\pi r^2 J_e = \pi r^2 J + 2\pi r J_s$$

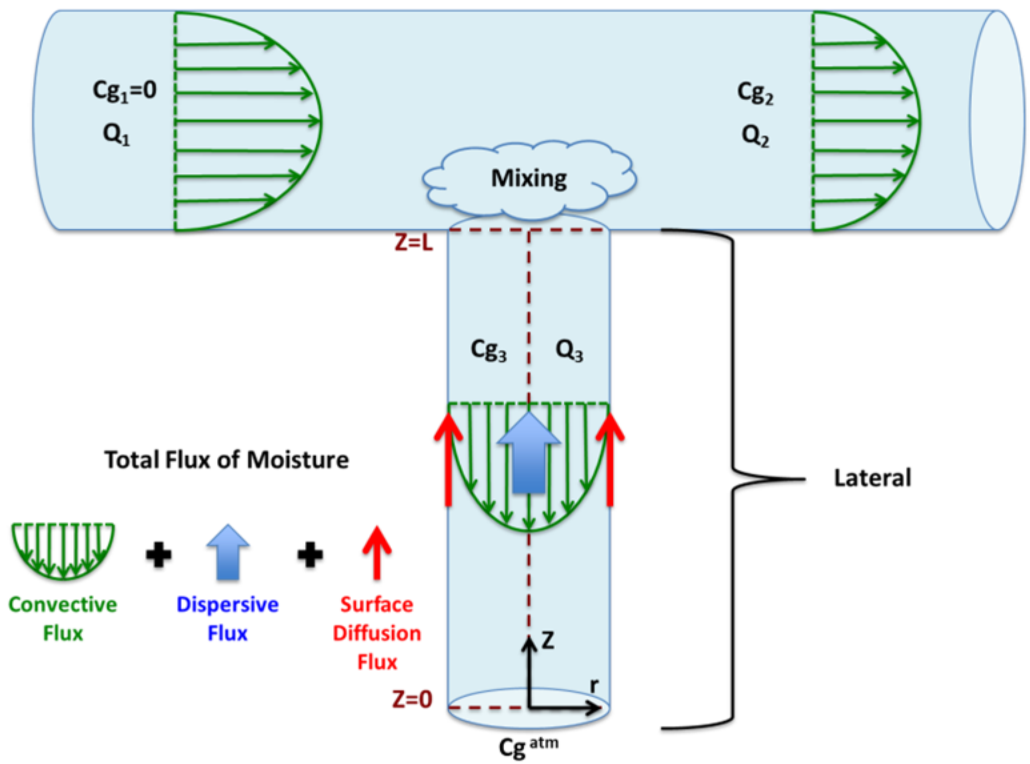
Effective Dispersion Coefficient

$$D_e = D + \frac{2}{r}D_s K_e$$

Governing Equation

Convection; Effective Dispersion

$$\underbrace{U_3\frac{dC_g}{dz}}_{\text{Convection}} + \underbrace{D_e\frac{d^2C_g}{dz^2}}_{\text{Effective Dispersion}} = 0$$



Boundary Condition 1

$$z = 0, \qquad C_g = C_g^{atm}$$

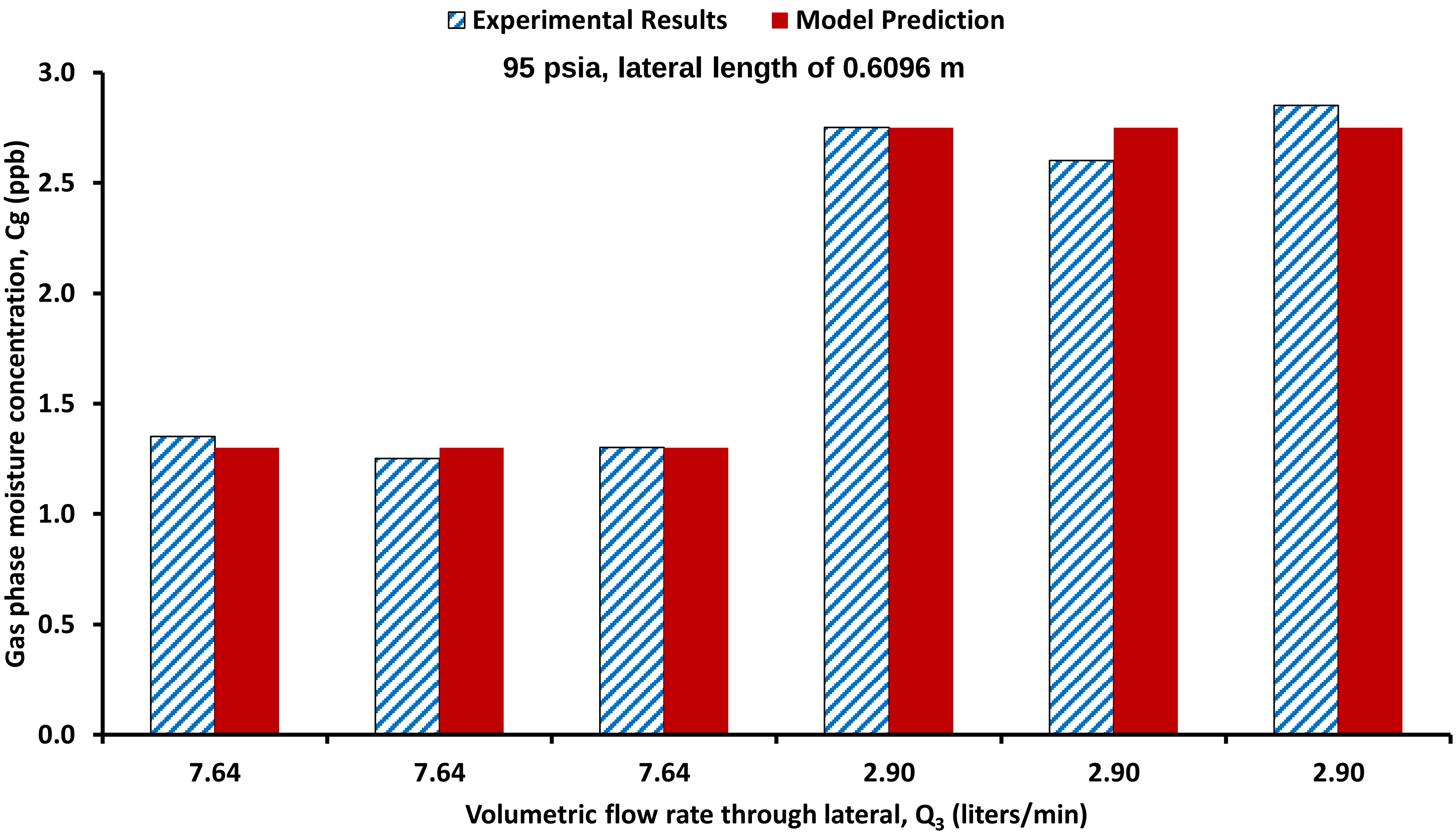
Boundary Condition 2

Convective Flux; Effective Dispersive Flux

$$z = L, \qquad C_g\Big|_{z=L} = \left(\underbrace{-U_3 C_g\Big|_{z=L}}_{\text{Convective Flux}} - \underbrace{D_e\frac{dC_g}{dz}\Big|_{z=L}}_{\text{Effective Dispersive Flux}}\right)\frac{A_{lateral}}{Q_2}$$

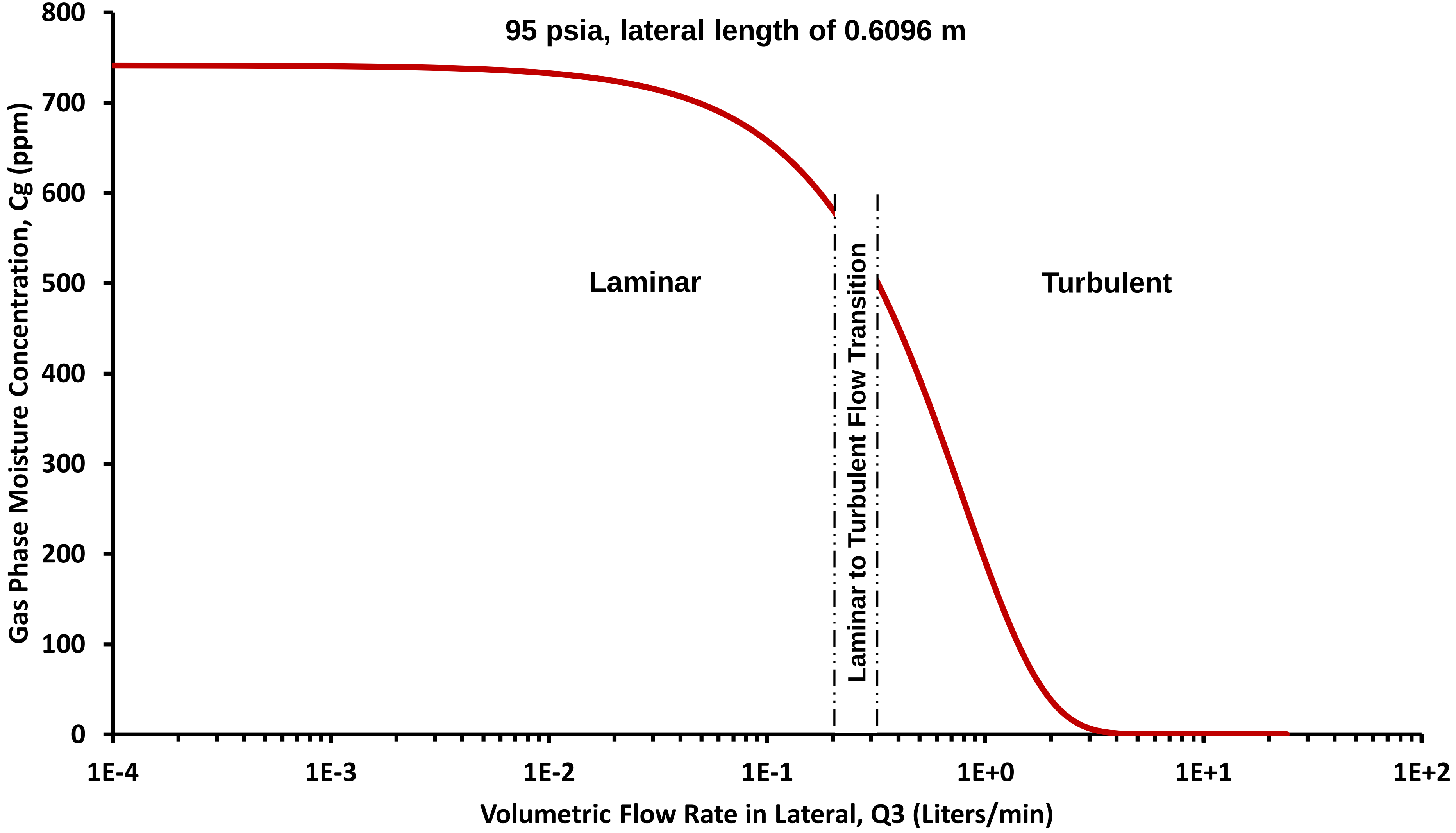
Process Simulator Verification

Simulator Prediction



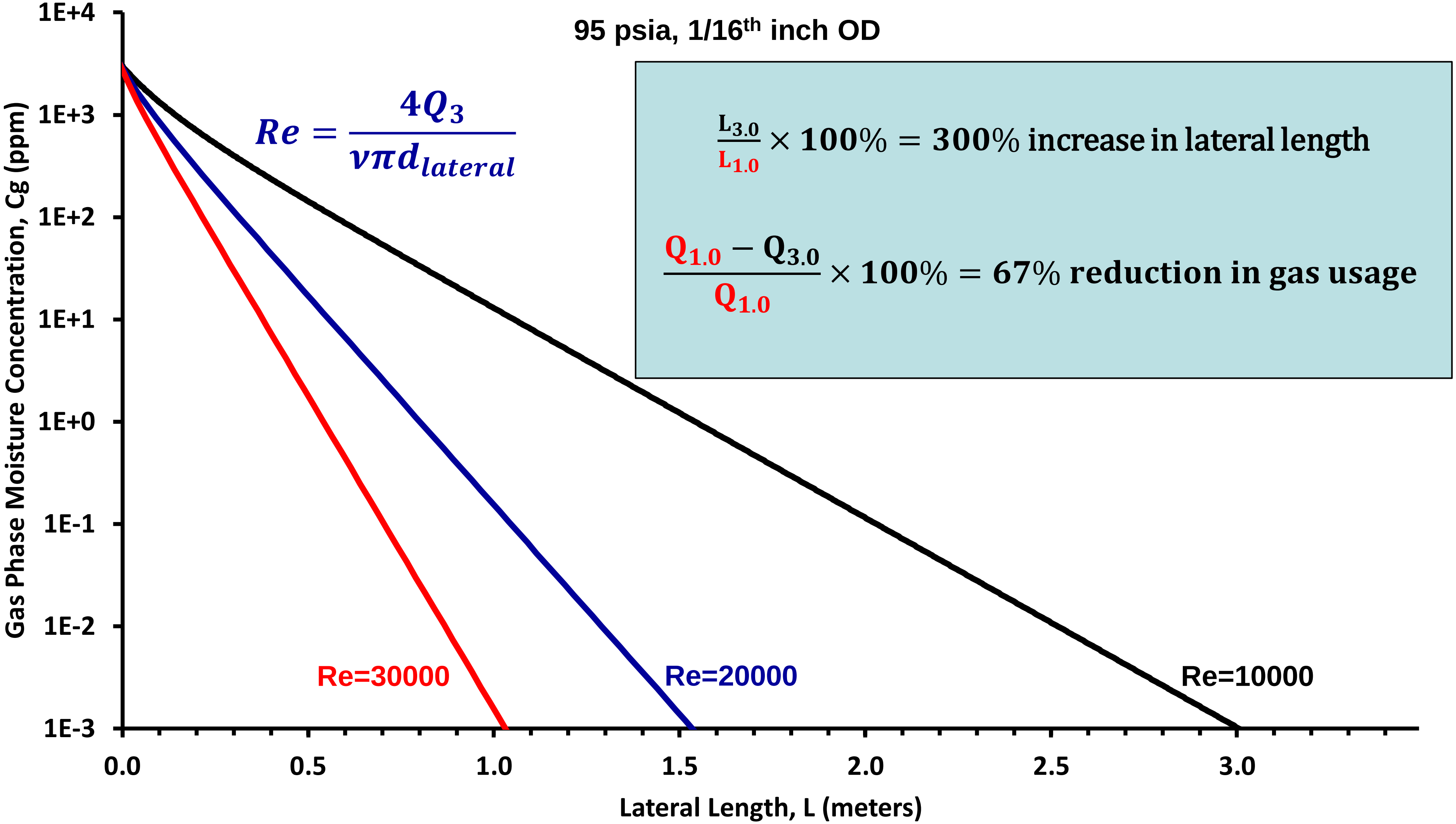
Parametric Studies

Effect of Flow Rate on Gas Phase Moisture



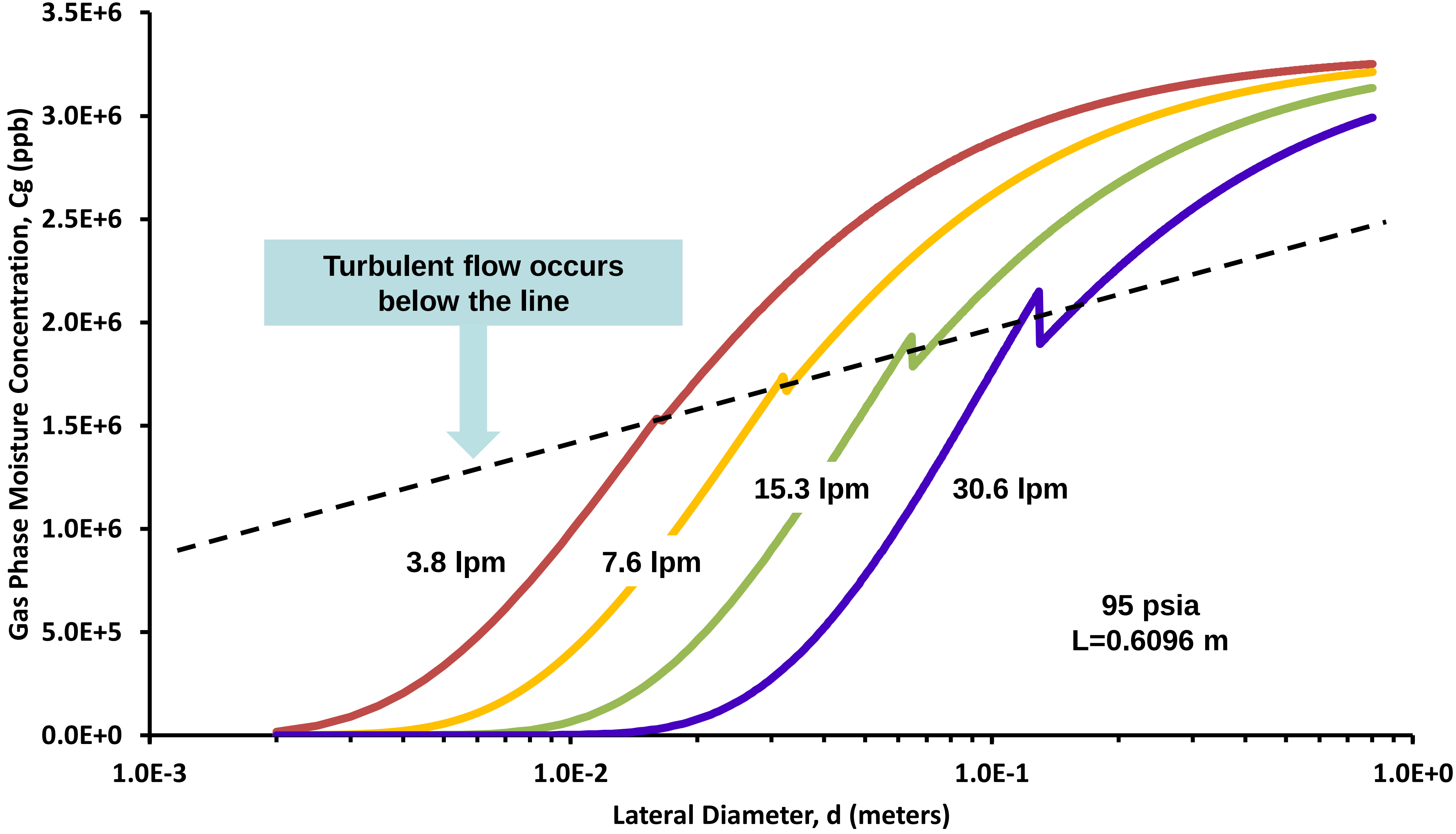
Parametric Studies

Effect of Lateral Length on Gas Phase Moisture



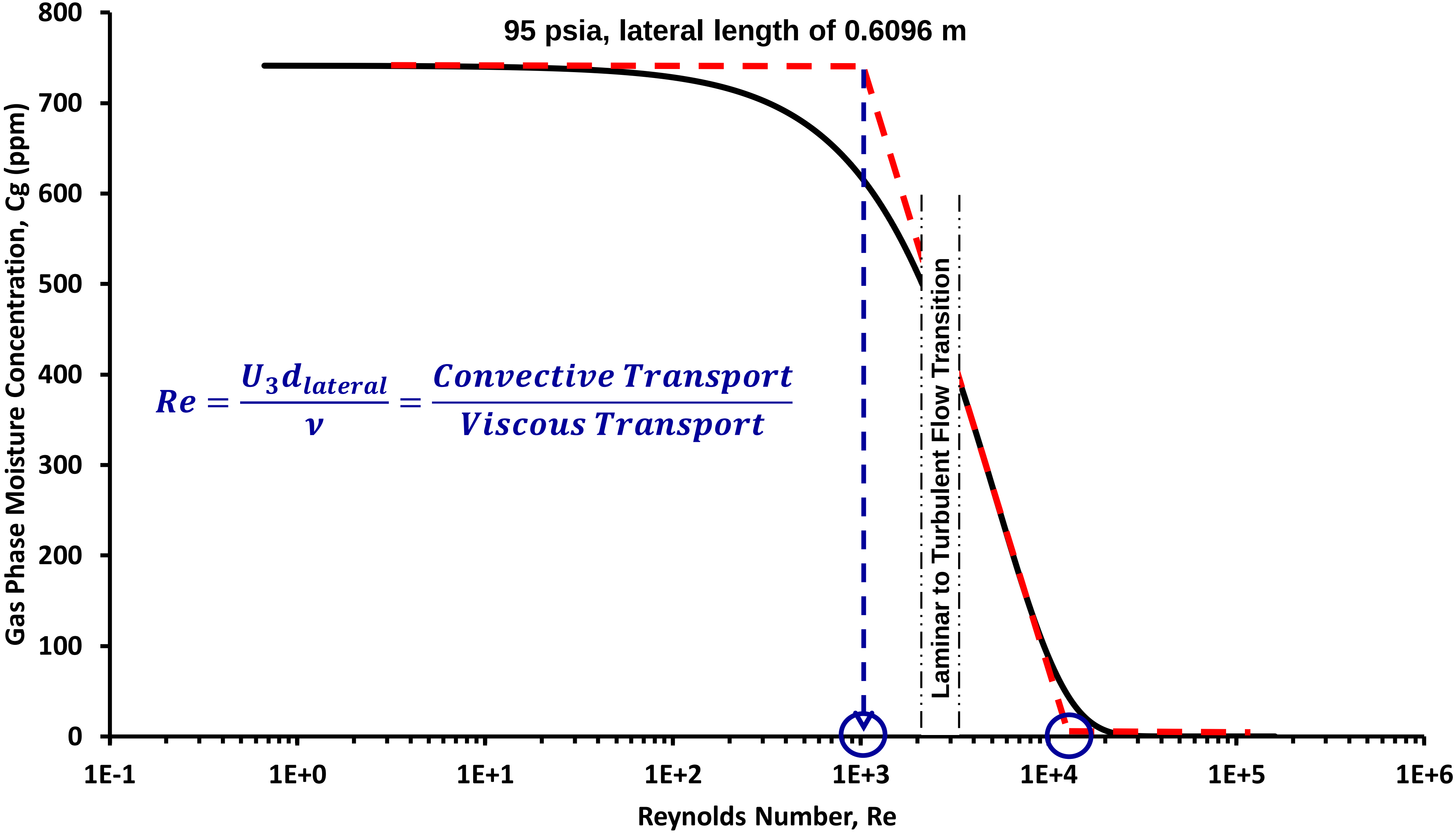
Parametric Studies

Effect of Lateral Diameter on Gas Phase Moisture



Parametric Studies

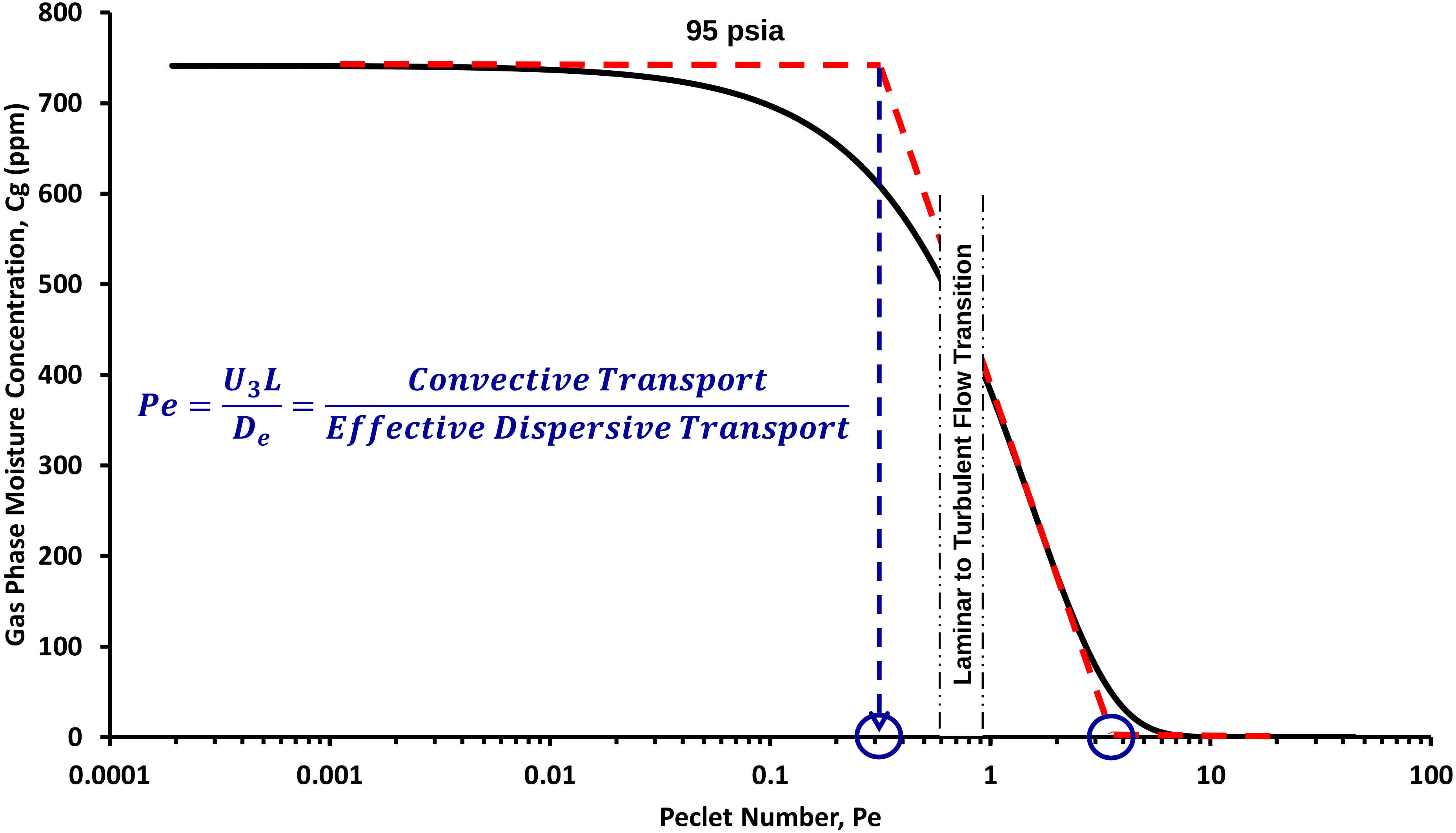
Effect of Reynolds Number on Gas Phase Moisture



$$Re = \frac{U_3 d_{lateral}}{\nu} = \frac{Convective\ Transport}{Viscous\ Transport}$$

Parametric Studies

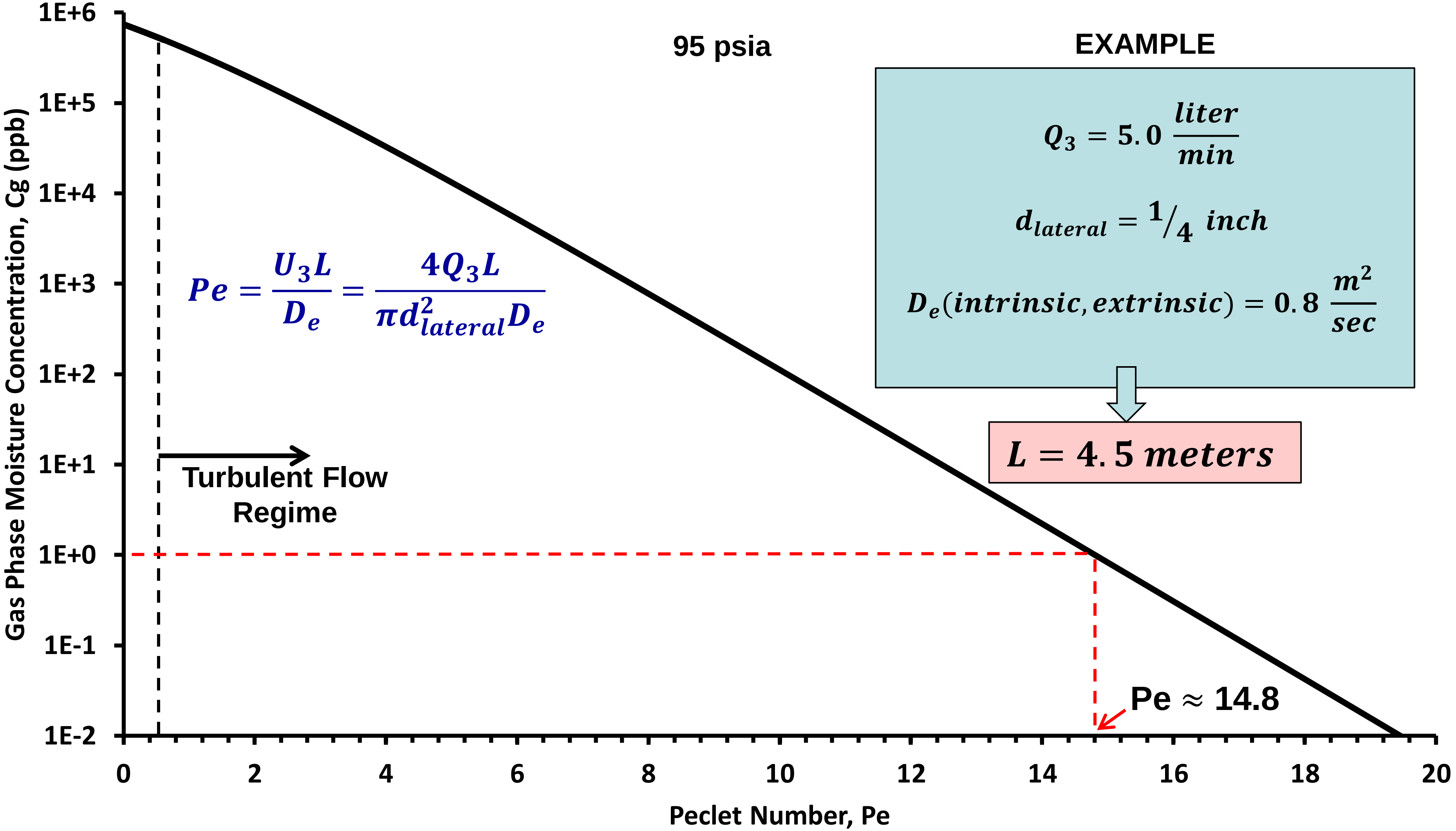
Effect of Peclet Number on Gas Phase Moisture



$$Pe = \frac{U_3 L}{D_e} = \frac{Convective\ Transport}{Effective\ Dispersive\ Transport}$$

Parametric Studies

Effect of Peclet Number on Gas Phase Moisture



Back Diffusion Process Simulator: Orifice Addition

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Gas Phase Dispersive Flux

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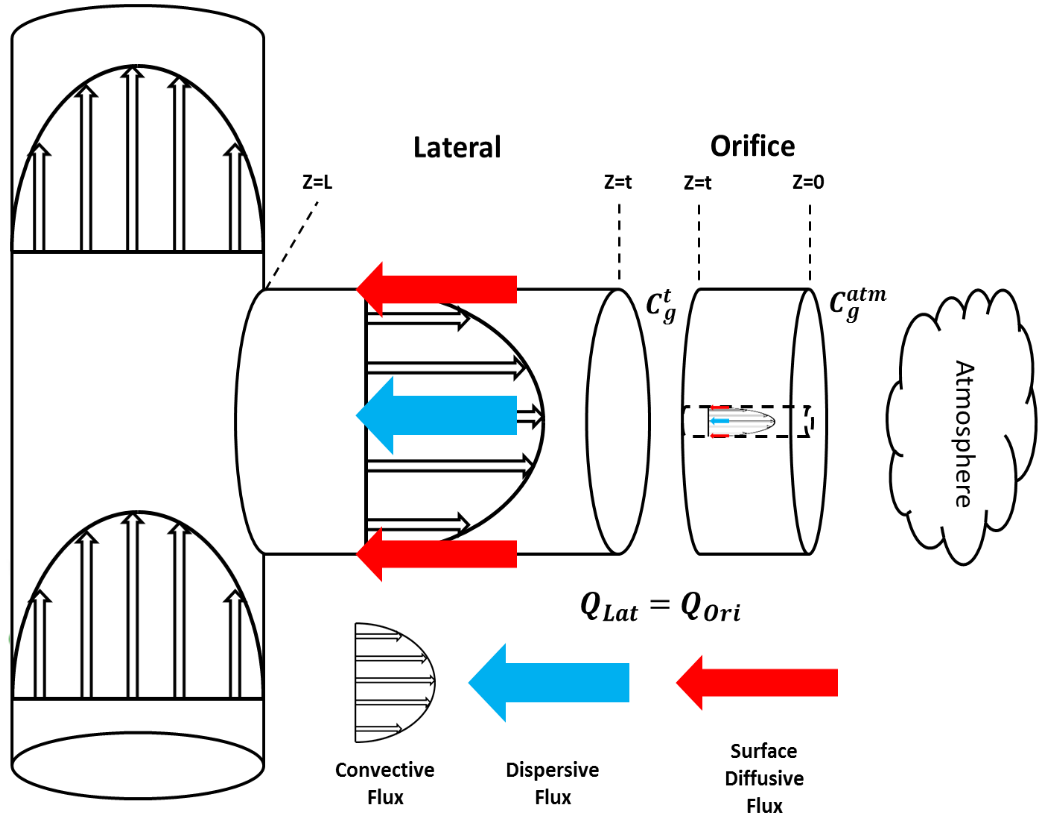


Boundary Condition 1

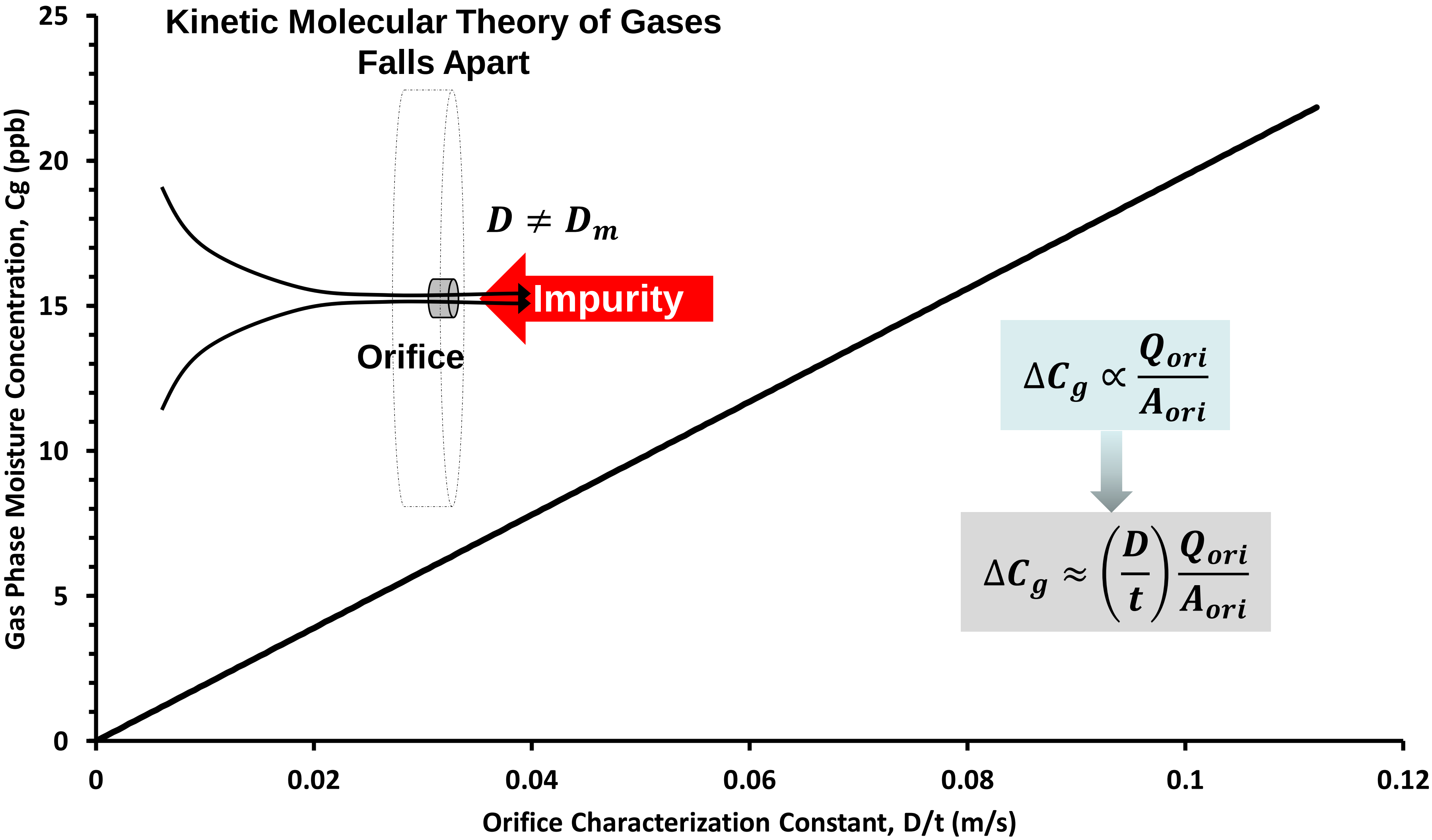
$$z = 0, \qquad D_m \left(\frac{C_g^{atm} - C_g}{t} \right) = \frac{Q_3}{A_{ori}} C_g$$

Boundary Condition 2

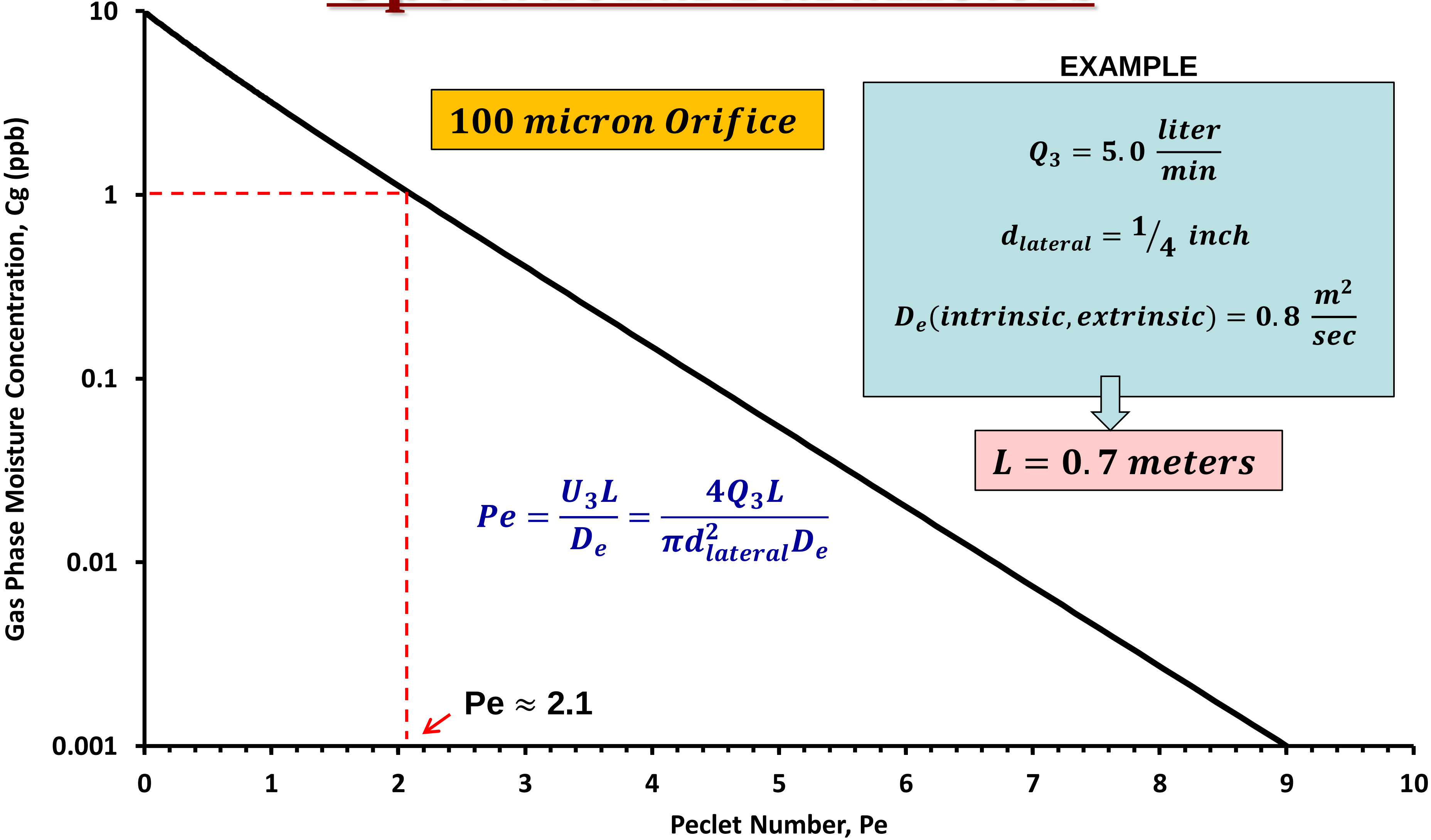
Convective Flux; Effective Dispersive Flux

$$z = L, \qquad C_g \Big|_{z=L} = \Bigg(\underbrace{-U_3 \, C_g \Big|_{z=L}}_{\text{Convective Flux}} - \underbrace{D_e \frac{dC_g}{dz} \Big|_{z=L}}_{\text{Effective Dispersive Flux}} \Bigg) \frac{A_{lateral}}{Q_2}$$

Orifice Addition to Simulator



Orifice Impact on Design and Operational Parameters



EXAMPLE

$$Q_3 = 5.0\ \frac{liter}{min}$$

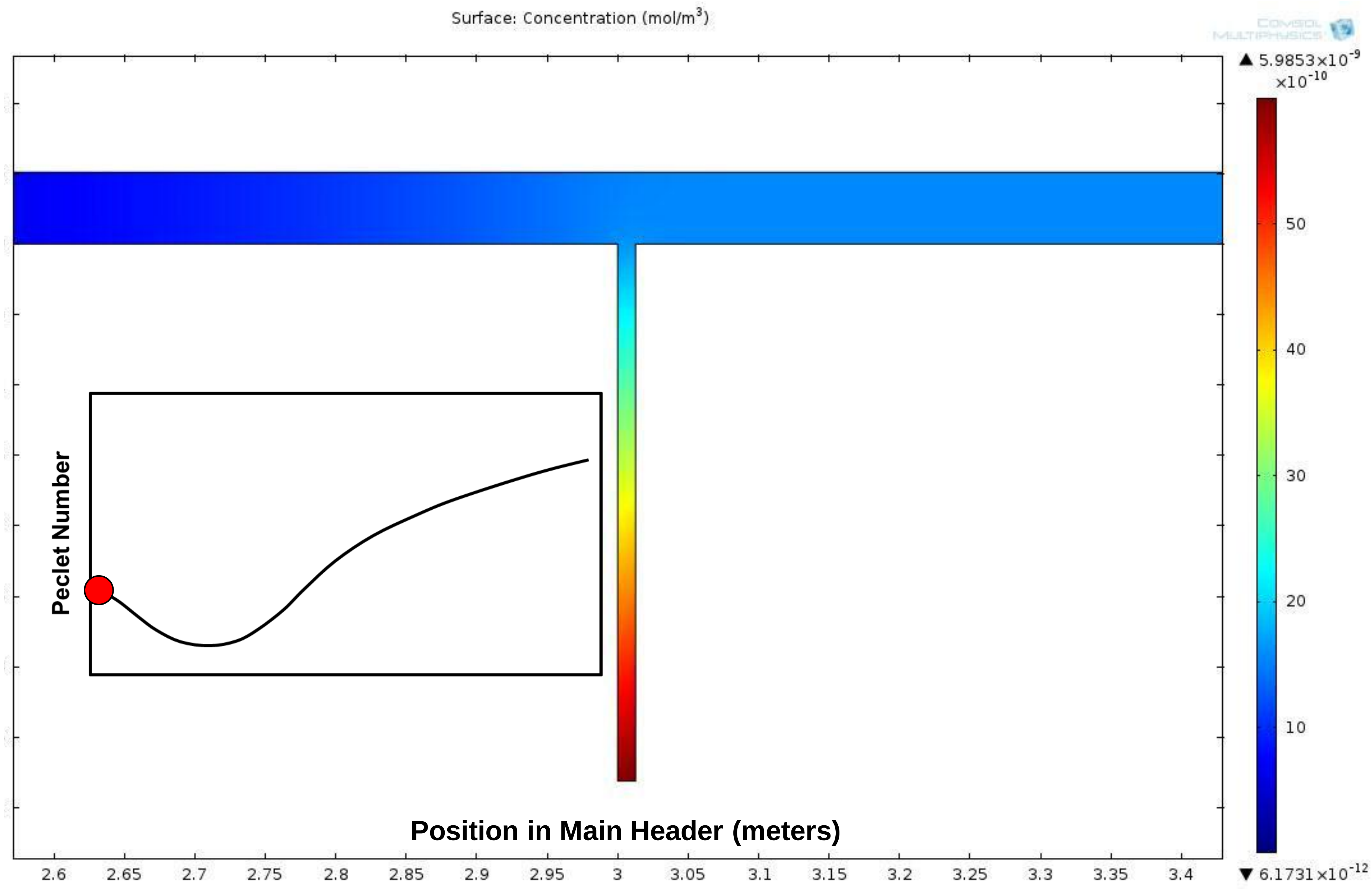
$$d_{lateral} = {}^{1}/_{4}\ inch$$

$$D_e(intrinsic, extrinsic) = 0.8\ \frac{m^2}{sec}$$

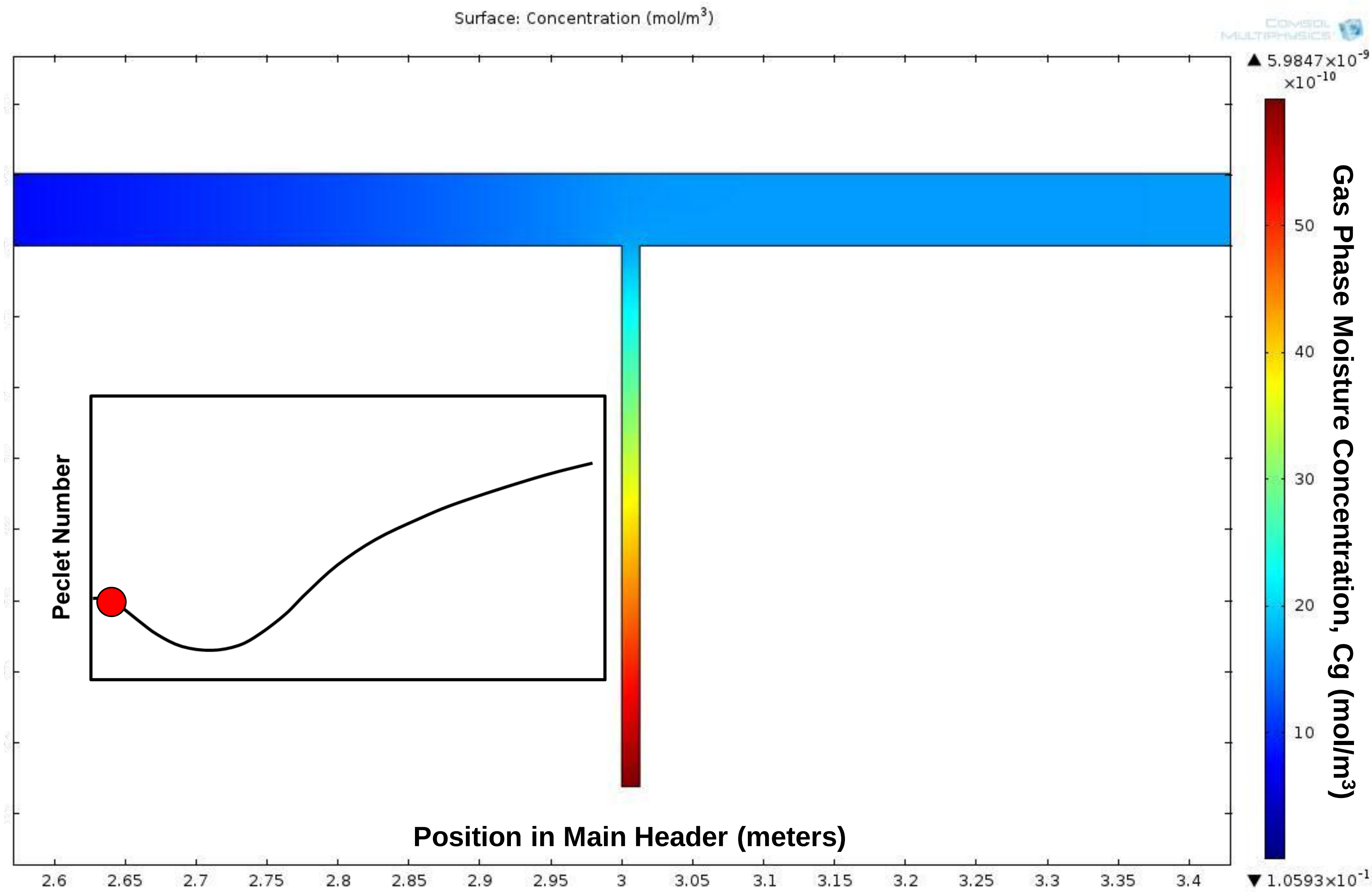
$$L = 0.7\ meters$$

$$Pe = \frac{U_3 L}{D_e} = \frac{4 Q_3 L}{\pi d_{lateral}^2 D_e}$$

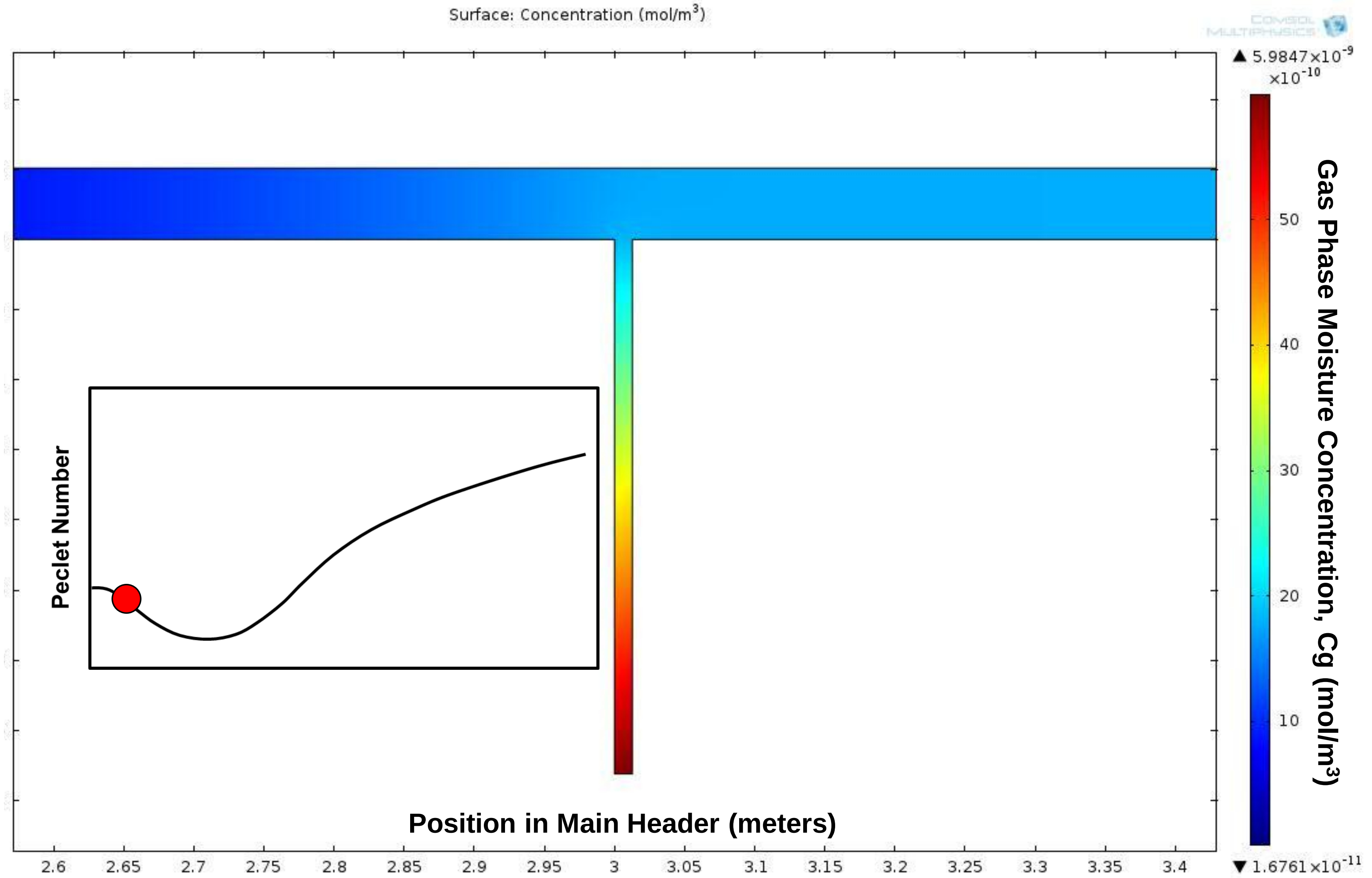
Simulation: 1



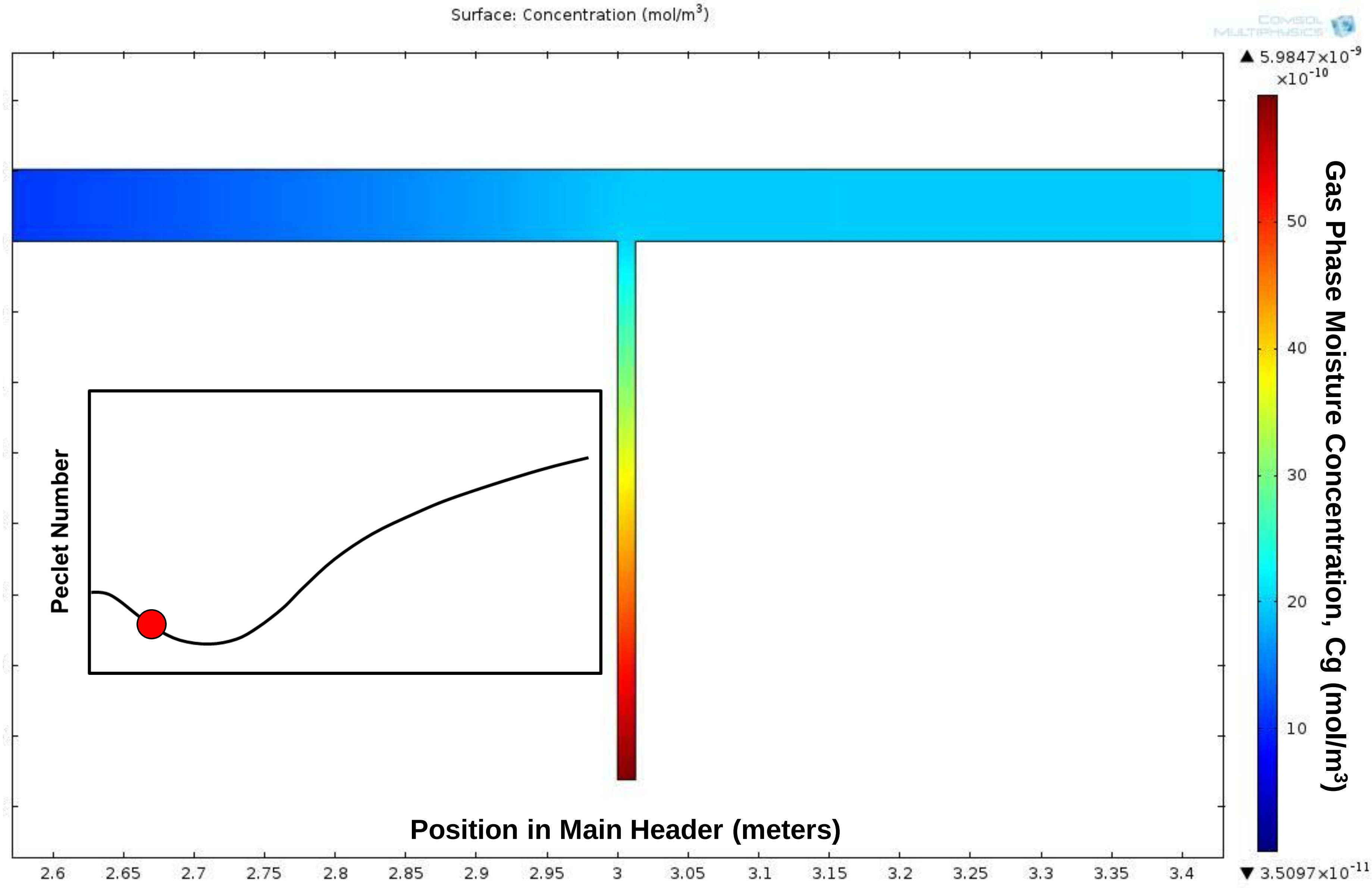
Simulation: 2



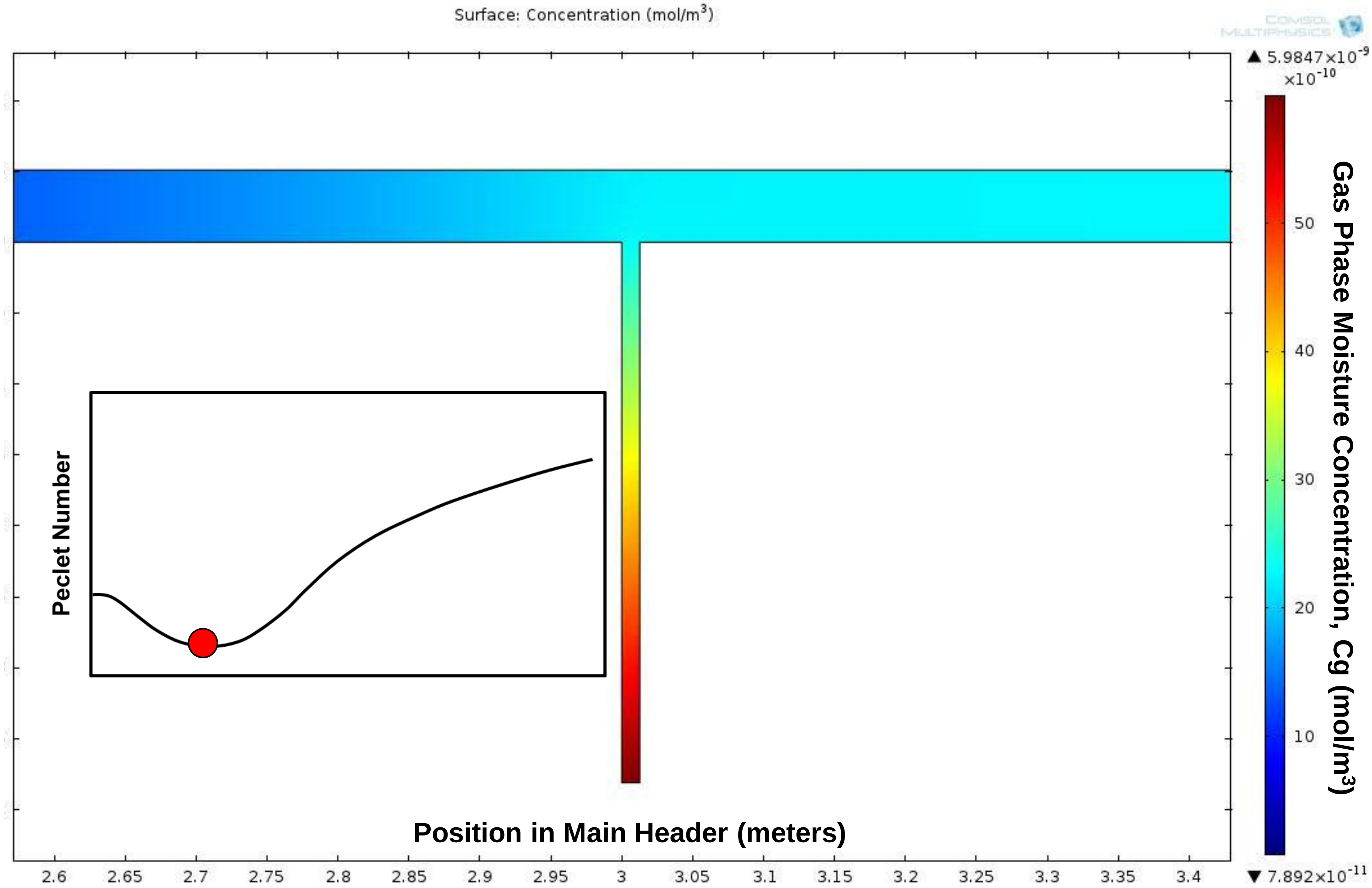
Simulation: 3



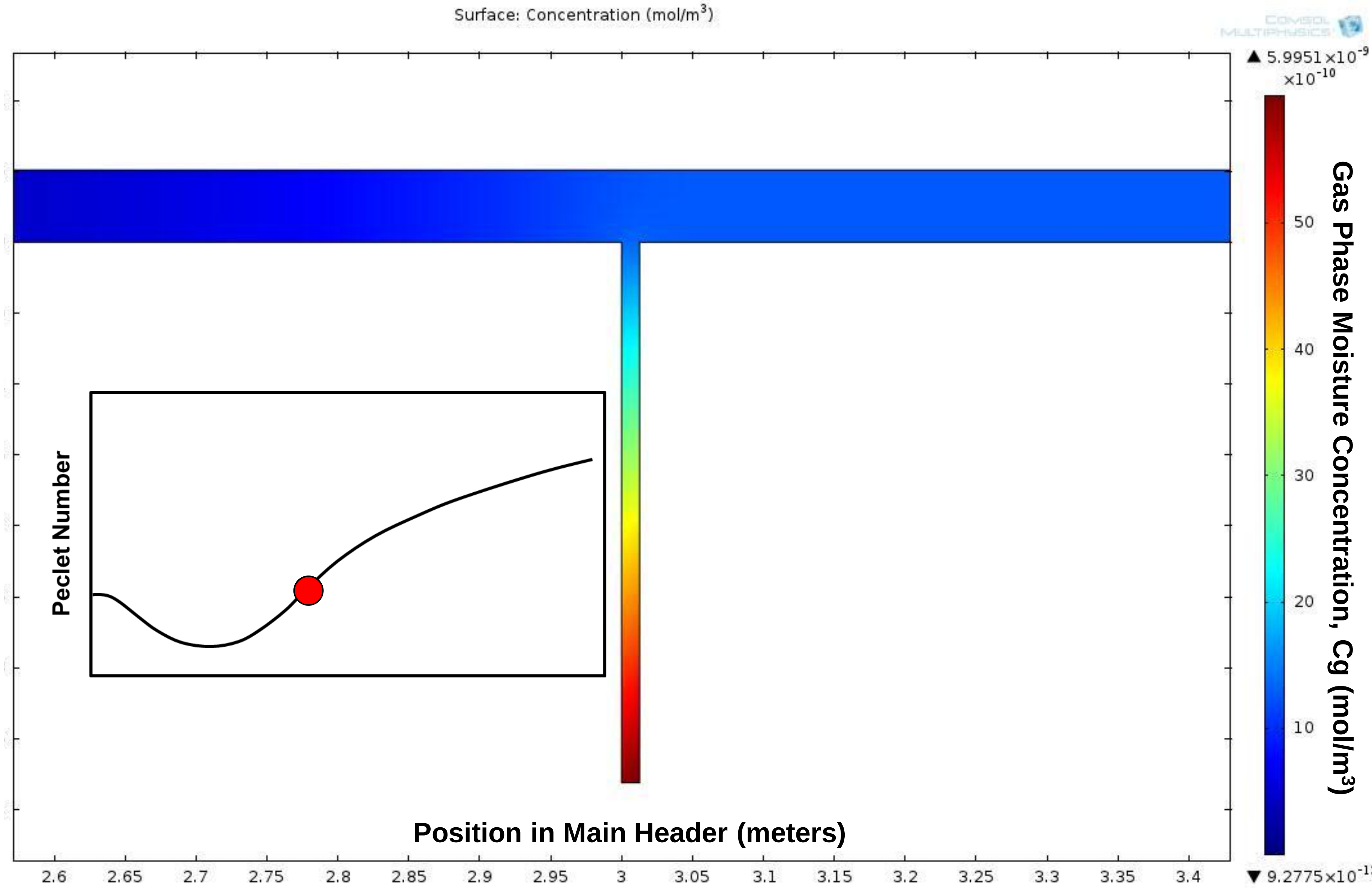
Simulation: 4



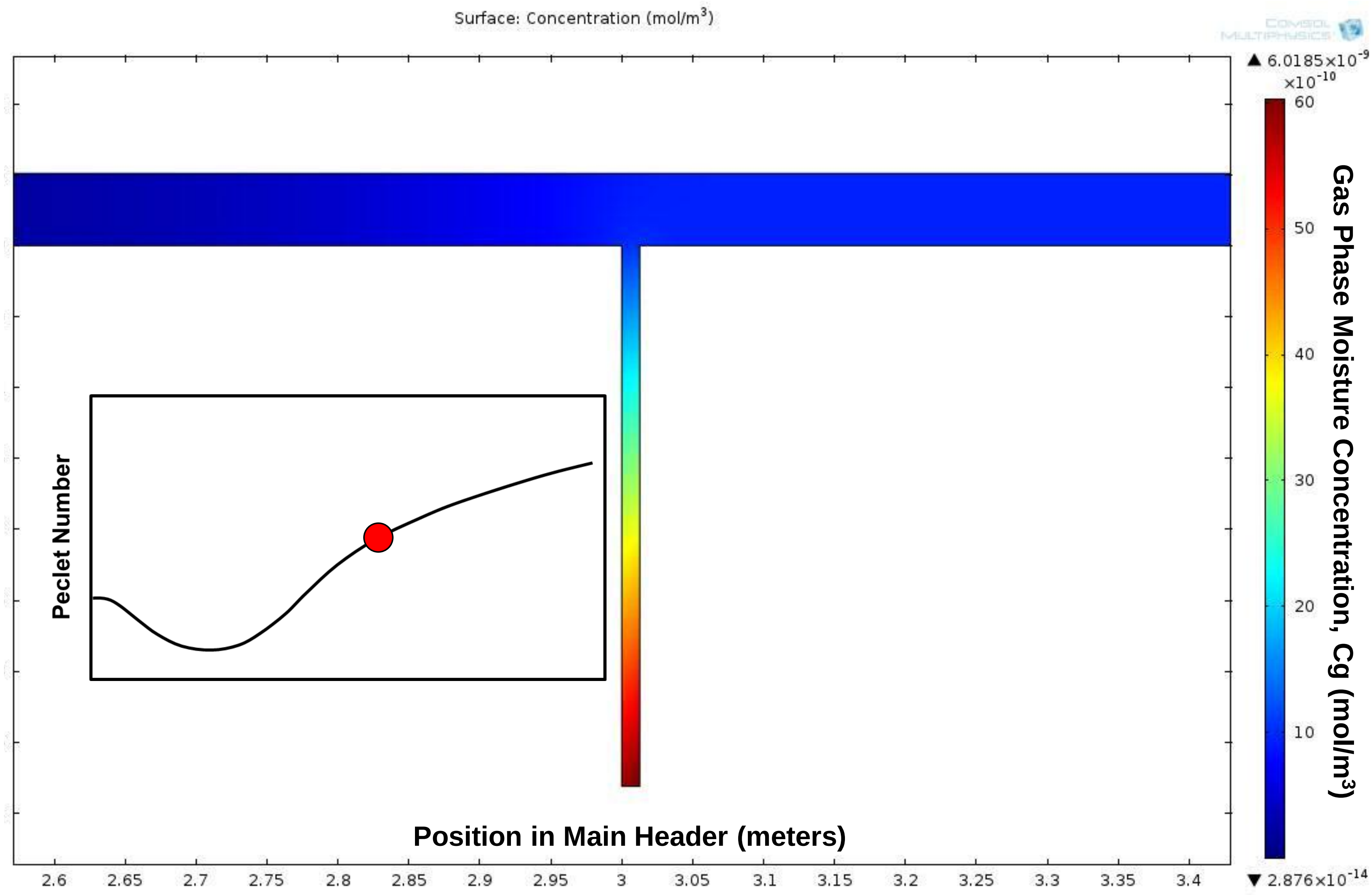
Simulation: 5



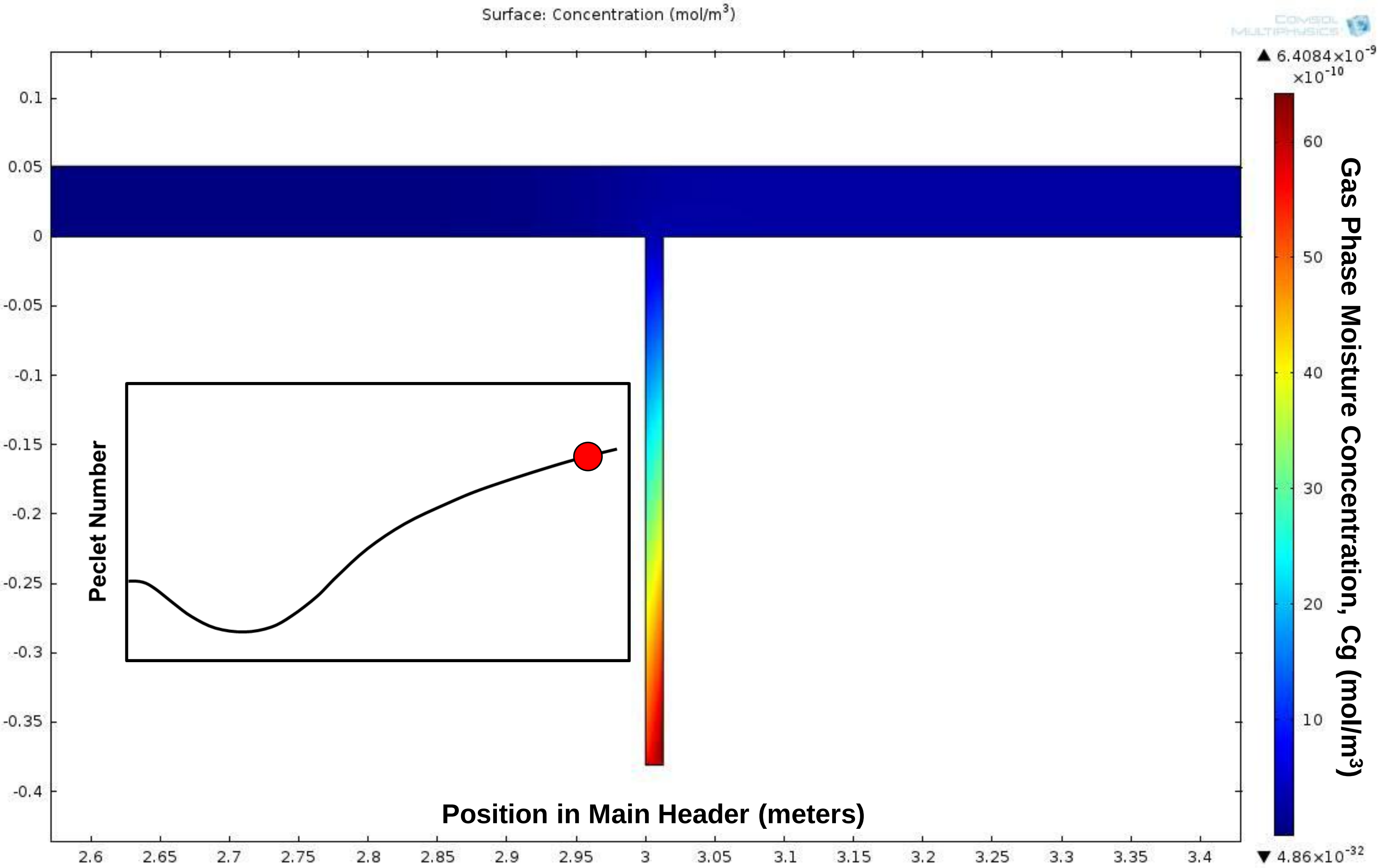
Simulation: 6



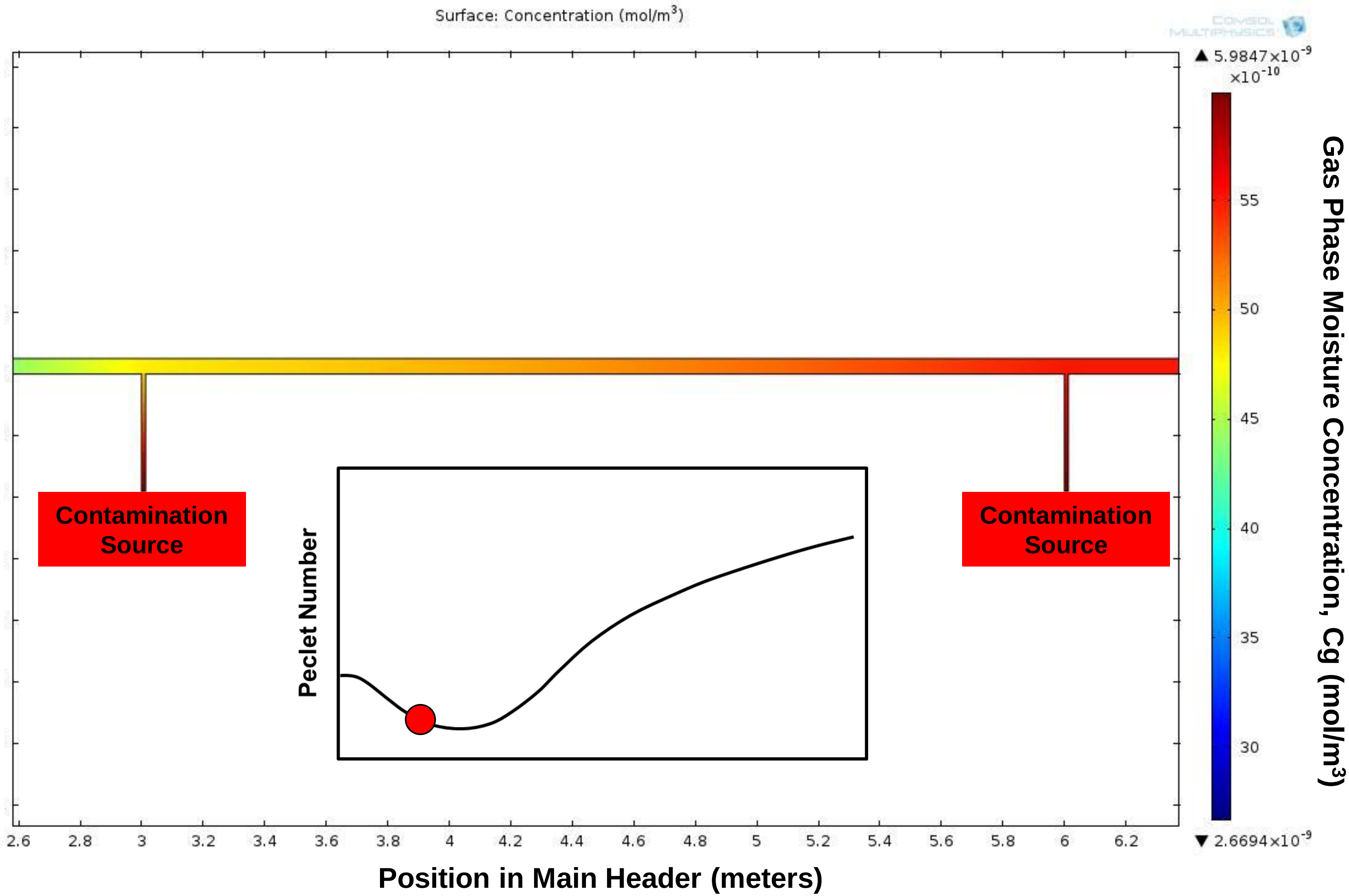
Simulation: 7



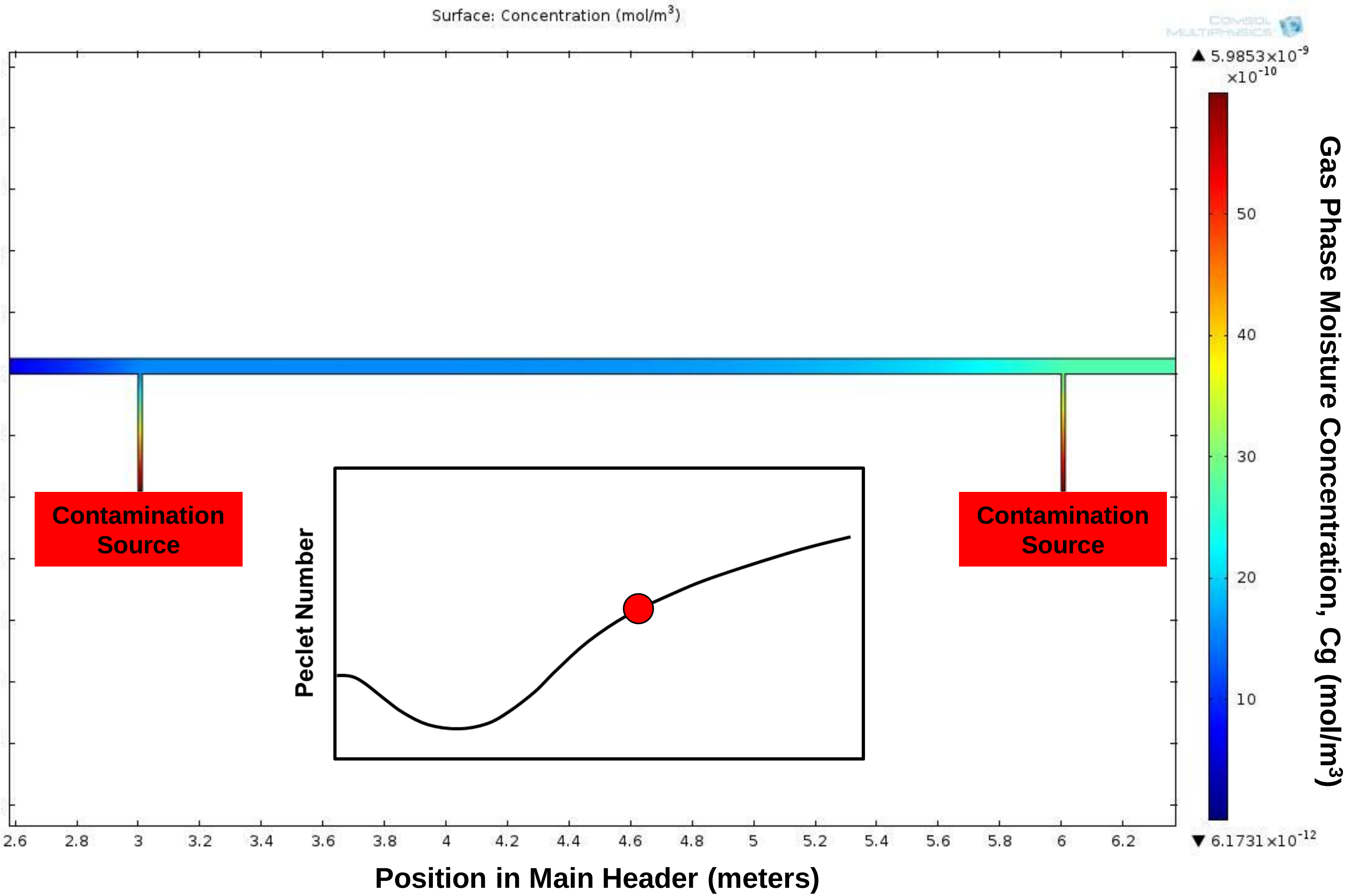
Simulation: 8



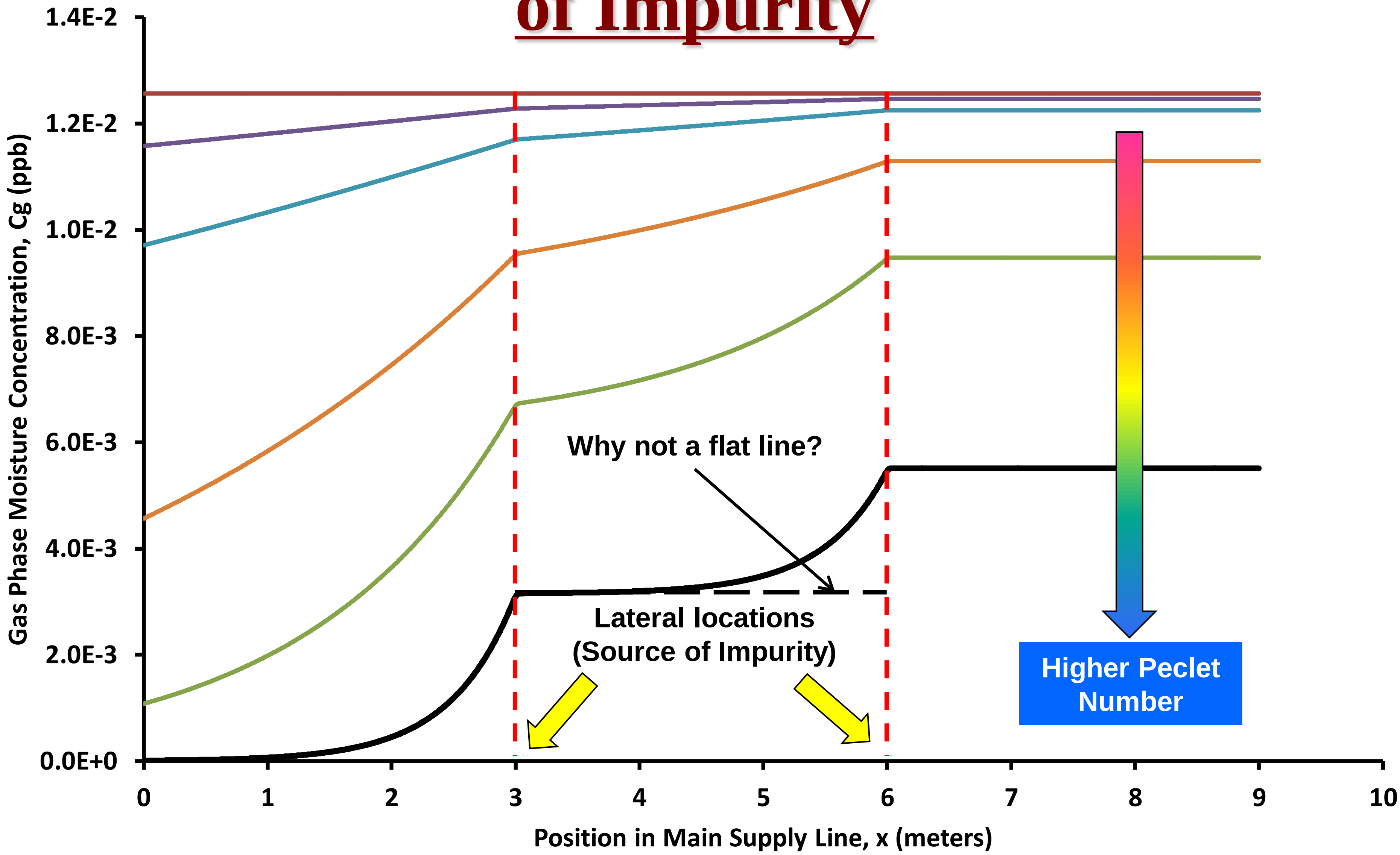
Simulation: 9



Simulation: 10



Compounding Effect of Multiple Sources of Impurity



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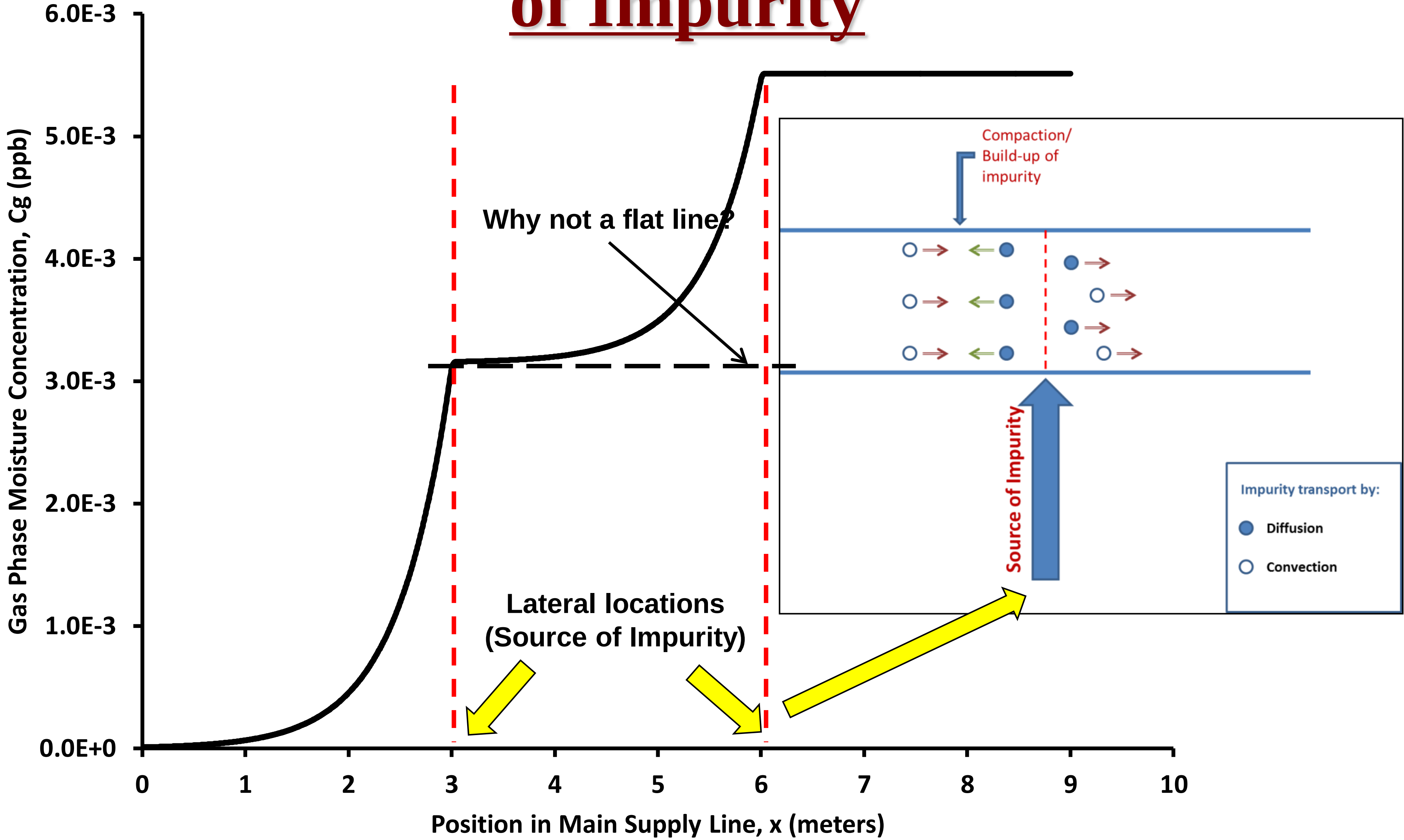
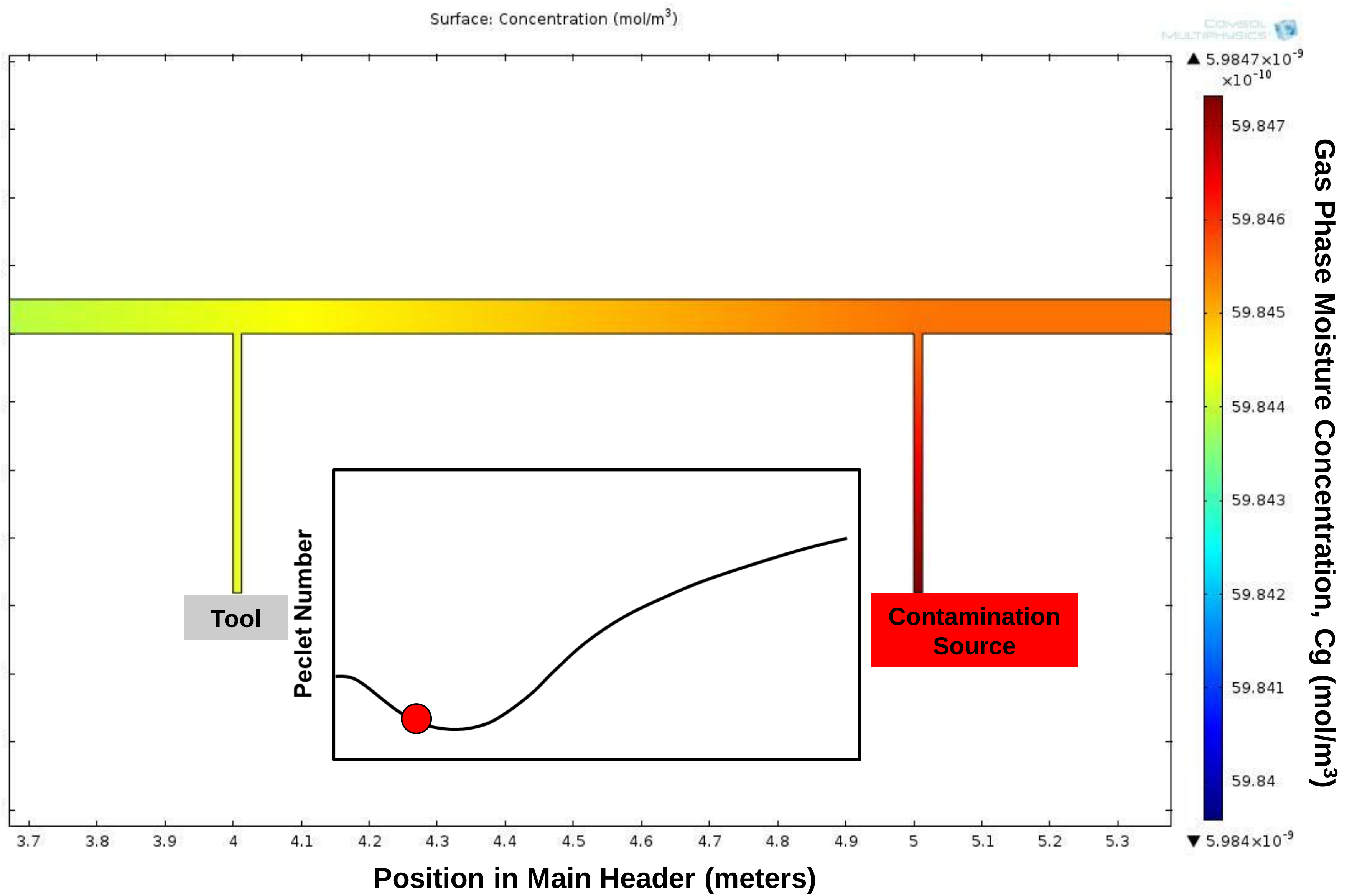
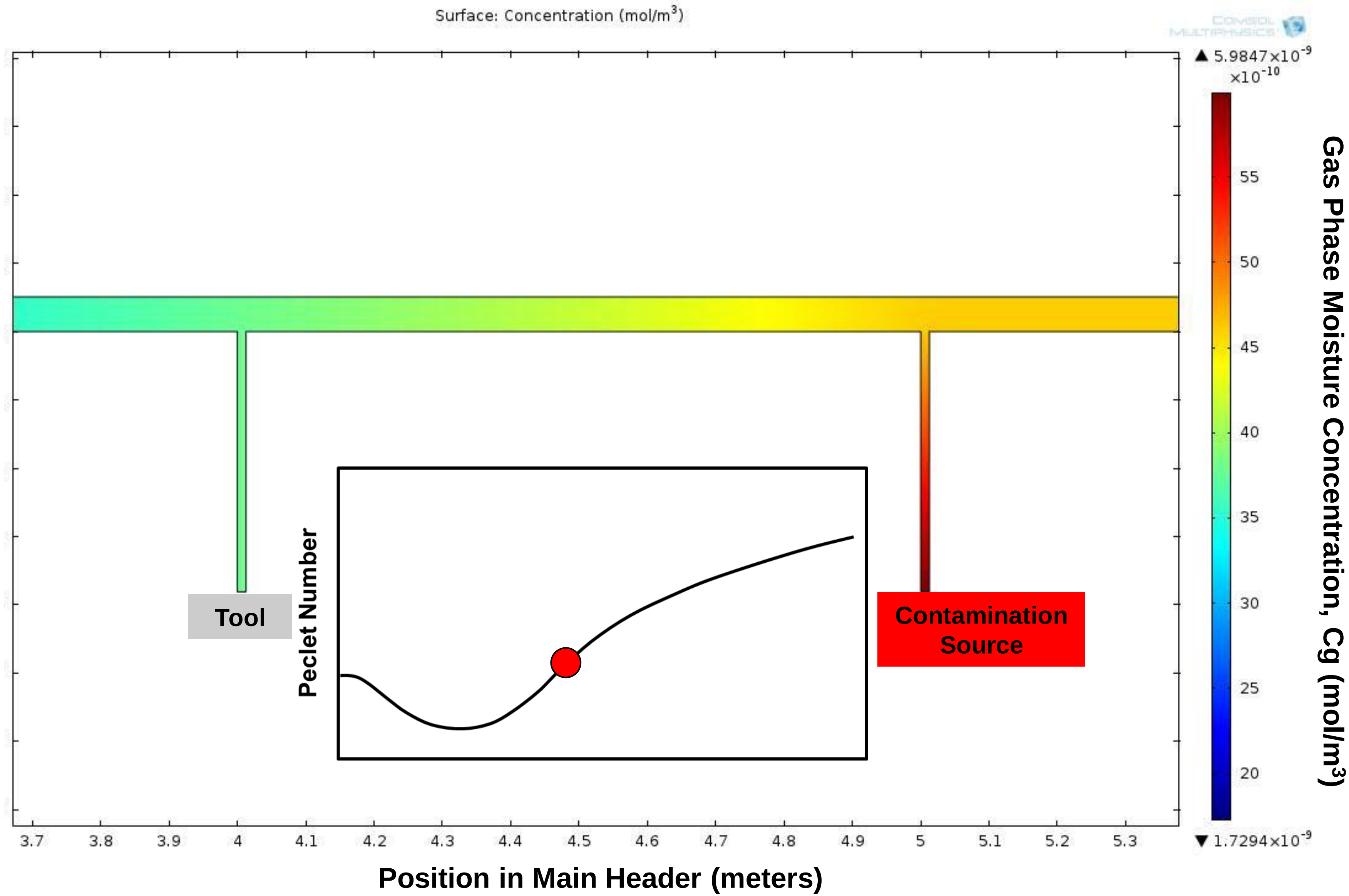


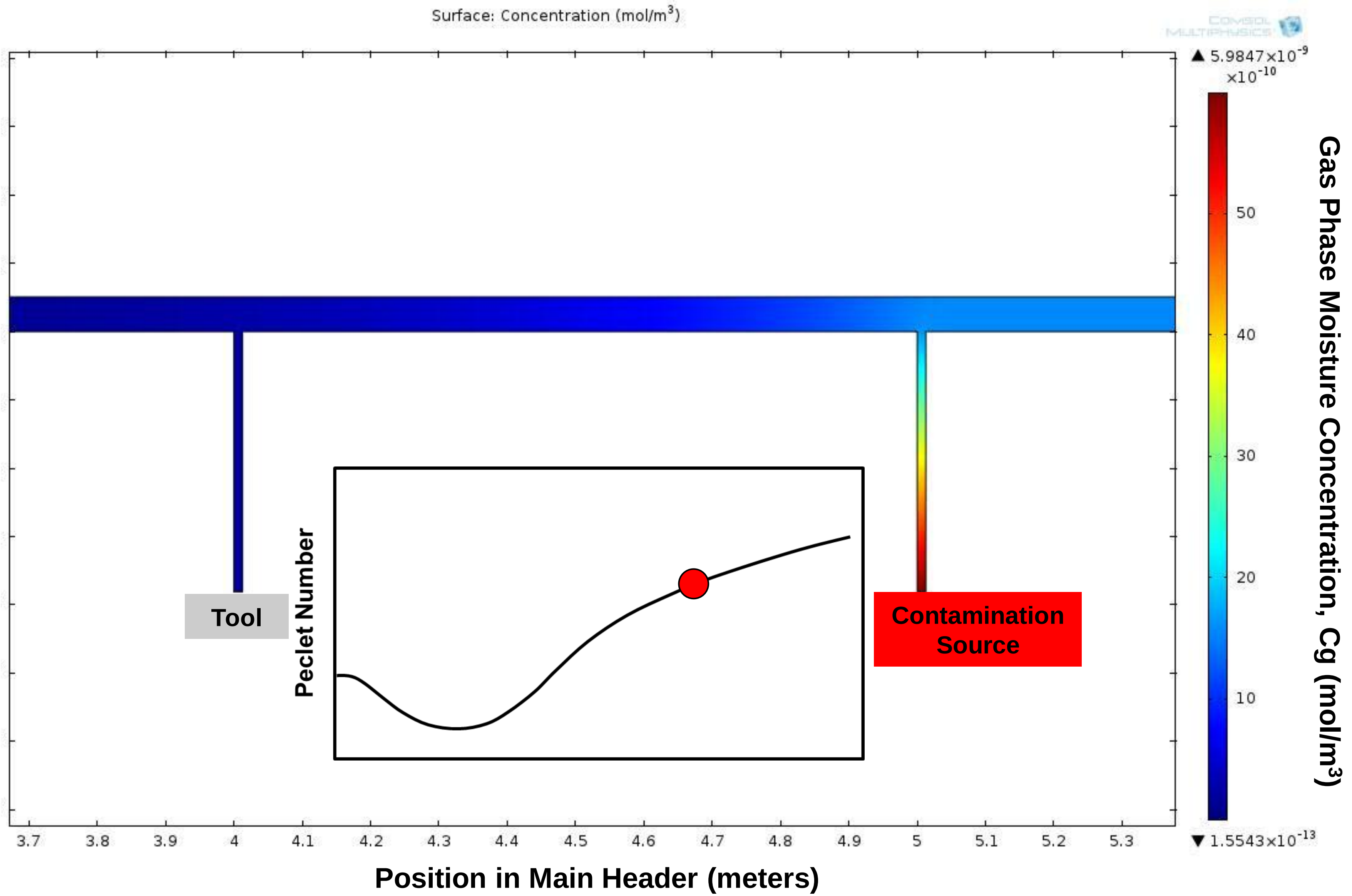
Simulation: 11



Simulation: 12



Simulation: 13



Highlights

- The experimental approach allowed for the observation of back diffusion in an adjustable and controllable manner.
- The process model accurately predicted experimental results and was invaluable in performing parametric studies.
- The moisture contamination due to back diffusion was a strong function of lateral diameter, length, and gas flow rate through the lateral.
- Characteristic groups were identified that allowed us to present generalized correlations that would help in the design and operation of UHP fluidic systems being exposed to a source of contamination
- This methodology was expanded to include an orifice and lateral in series and was effective in determining a design approach that will safeguard against the back diffusion of impurities into both bulk and process gases.
- The simulator showed flexibility in regards to being able to predict contaminant transport in systems with multiple sources of contamination as well as predicting the impact of such contamination on neighboring tools.

Industrial Interactions and Future Plans

- Continue our work with Intel on novel impurity control strategies to reduce gas usage
- Making the process simulator available to industry
- Extending the present study to other fluids, contaminants, and components

Acknowledgements

- Carl Geisert, Intel
- Tiger Optics support team