Methods for Reducing UHP and Process Gas Usage in Fabs

Customized Project, Sponsored by Intel

Co-PIs:

- **Farhang Shadman, Chemical Engineering, UA**
- **Carl Geisert, Intel**

Graduate Students:

- **Jivaan Kishore: Ph.D. student, Chemical Engineering, UA**
- **Roy Dittler (Ph.D. , graduated in 2014; currently with Intel)**

Undergraduate Students:

- **Andrew Jimenez, Chemical Engineering, UA**

Cost Sharing:

- **$45k (AZ-TRIF); $30k (membership funds); Equipment (Tiger Optics)**

Objective

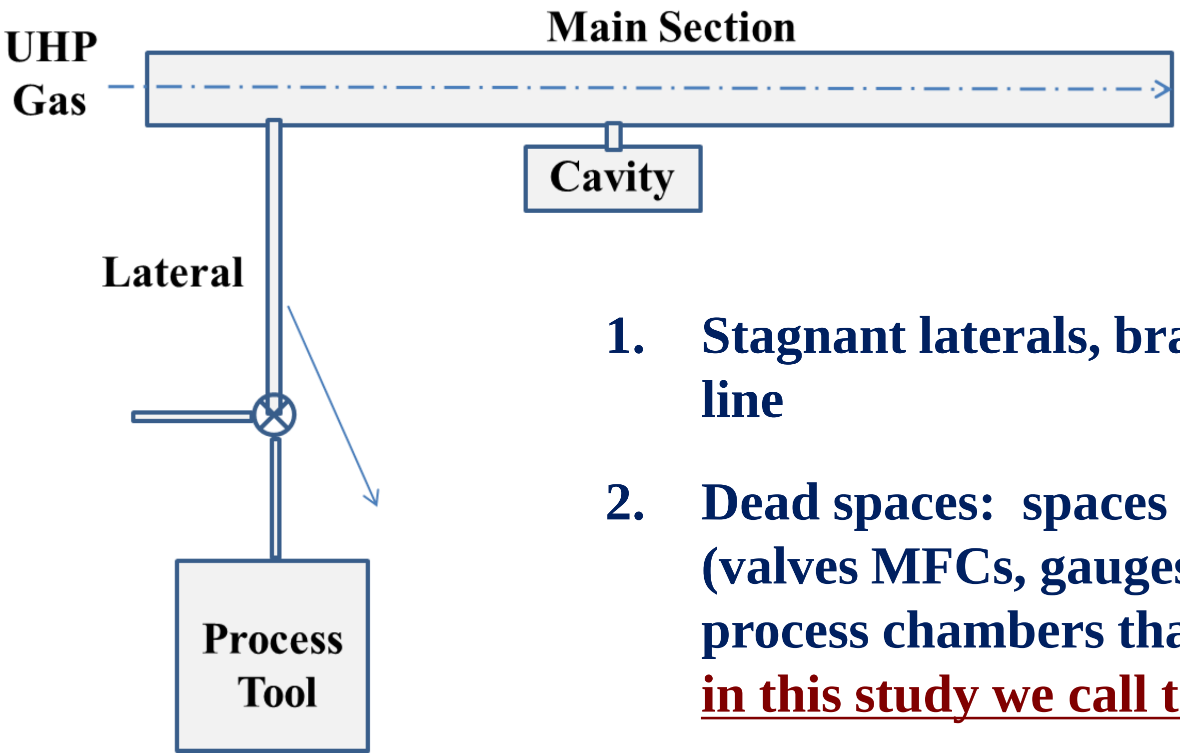
- **Phase 1: Lowering gas usage by minimizing "*back diffusion*" of impurities in UHP systems (*completed in 2014*)**
- **Phase 2: Novel methods for purging contaminants during steady operation, start-ups, or recovery from upsets.**
- **Phase 3: Reducing the usage of selected process gases.**

Motivation and ESH Impact

- **Efficient purge and contamination control in gas distribution systems and process chambers result in reducing the usage of expensive UHP bulk and process gases, increasing throughput, and lowering cost.**

Phase 2: Purging Laterals and Cavities

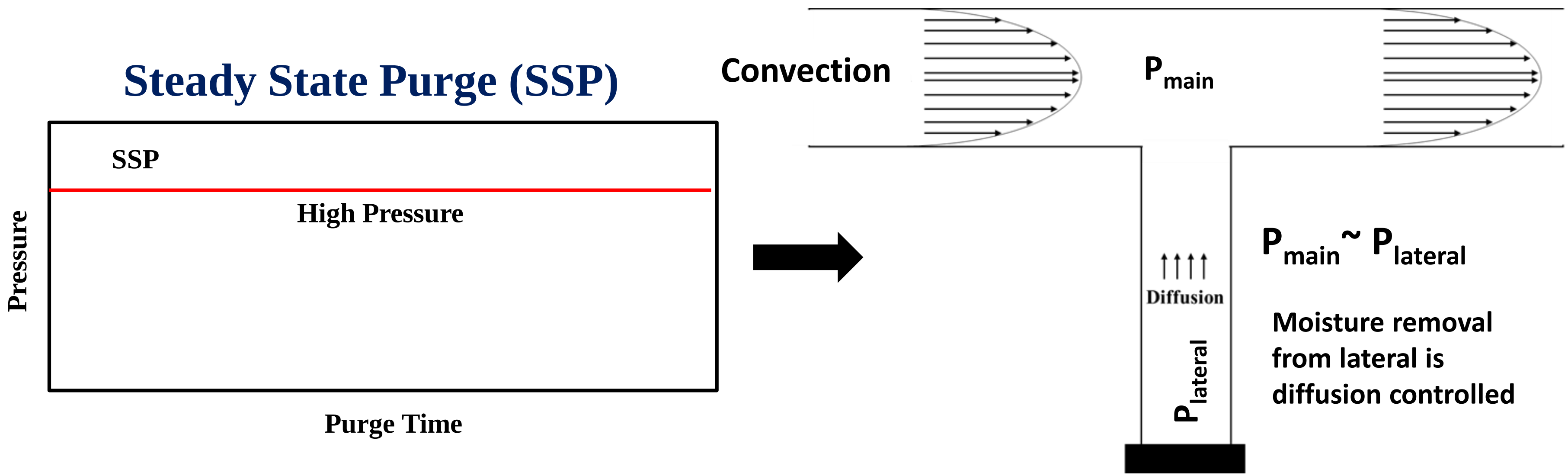
- **A large fraction of UHP gases in fabs is used for purging the gas distribution/delivery systems and process chambers during start up, gas switching, and for impurity removal.**



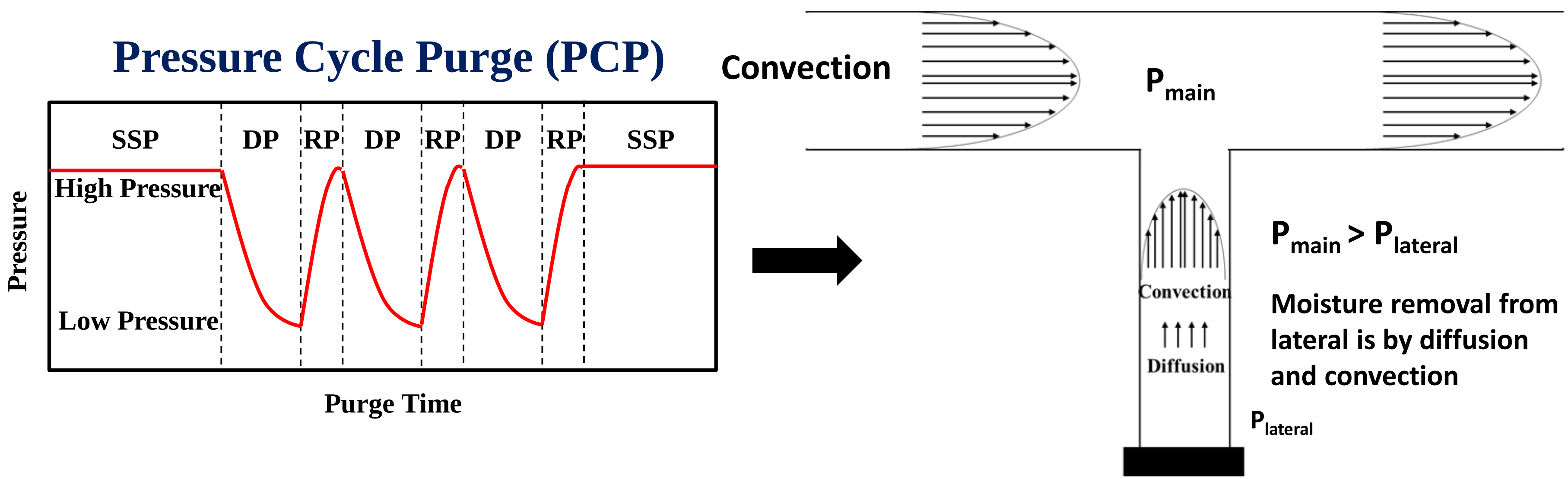
1. **Stagnant laterals, branching from the main line**
2. **Dead spaces: spaces in flow control devices (valves MFCs, gauges, fittings) and zones in process chambers that have low or no flow; in this study we call these spaces "*cavities*".**

Purge Techniques

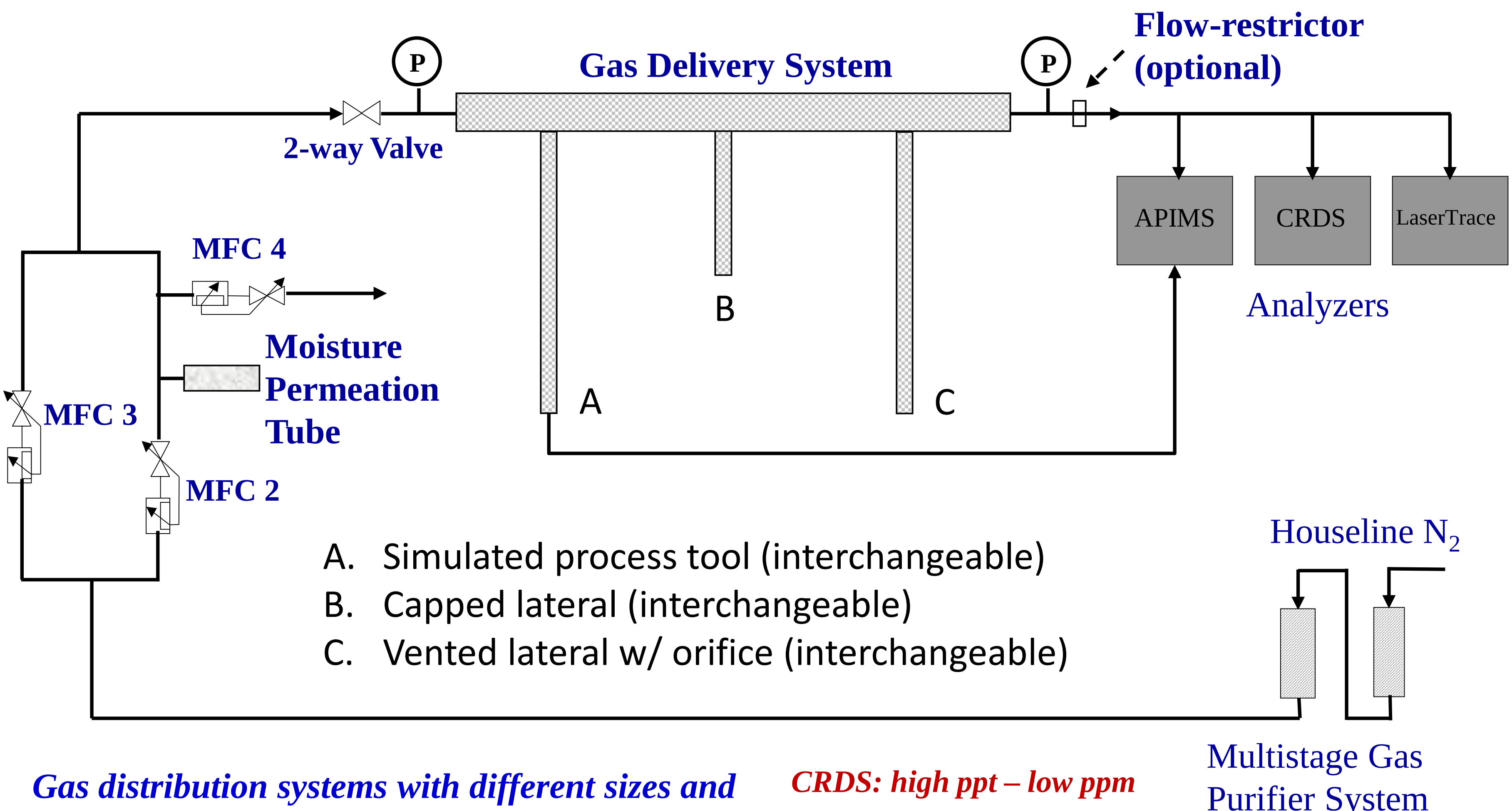
Steady State Purge (SSP)



Pressure Cycle Purge (PCP)



Method of Approach: Experiment Testbed



A. Simulated process tool (interchangeable)
B. Capped lateral (interchangeable)
C. Vented lateral w/ orifice (interchangeable)

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

CRDS: high ppt – low ppm

APIMS: low ppt – low ppb

Method of Approach: Process Simulator

Continuity equation:

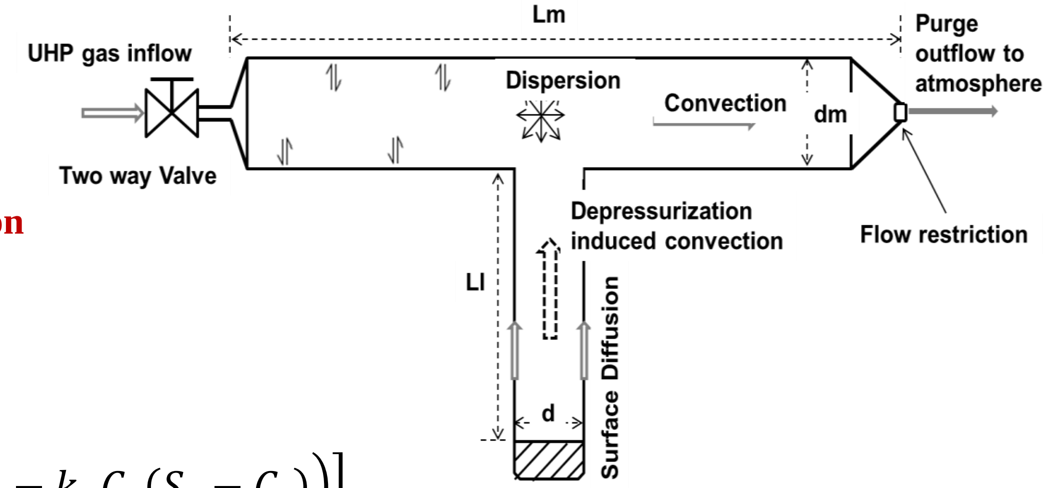
$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho V) = 0$$

Navier–Stokes equation:

$$\rho\left(\frac{\partial V}{\partial t} + V \cdot \nabla V\right) = -\nabla P$$

Moisture concentration on the pipe surface:

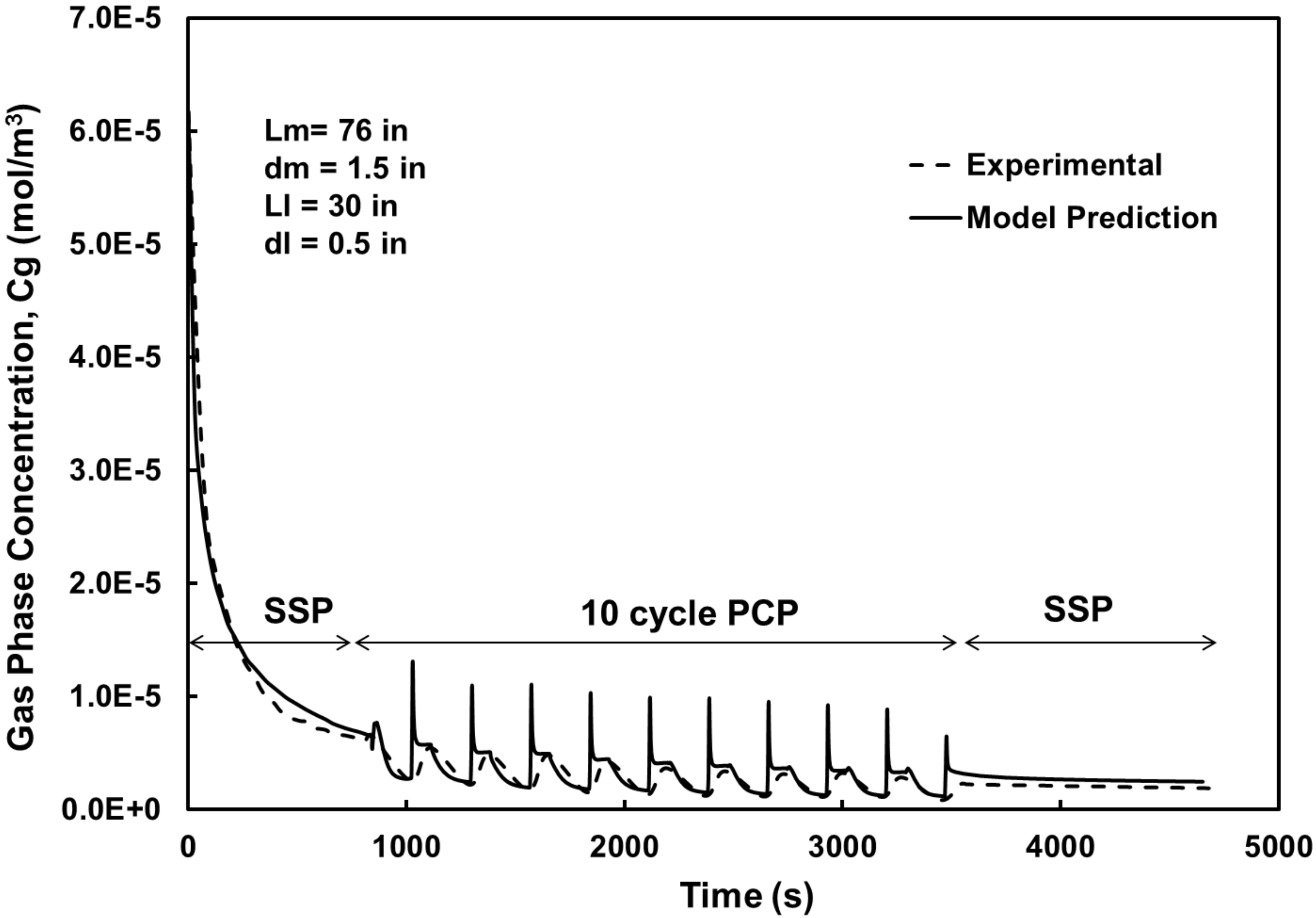
$$\frac{\partial C_s}{\partial t} = \underbrace{\nabla.(D_s \nabla C_s)}_{\text{Surface Diffusion}} + \underbrace{k_d C_s - k_a C_g (S_0 - C_s)}_{\text{Adsorption and desorption}}$$



Moisture concentration in the gas phase:

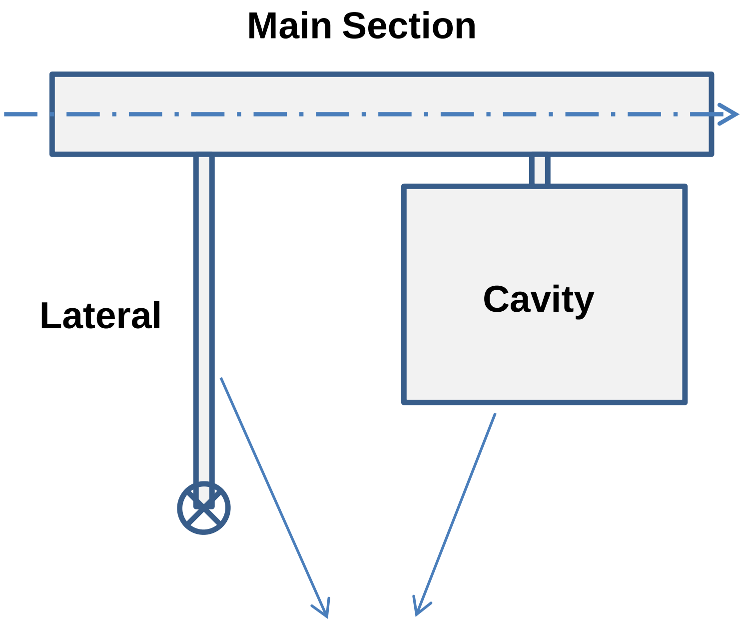
$$\frac{\partial C_g}{\partial t} + \underbrace{A\nabla.(uC_g)}_{\text{Convection}} = \underbrace{\nabla.(AD_e \nabla C_g)}_{\text{Diffusion}} + \underbrace{\frac{4}{d}\left[\left(k_d C_s - k_a C_g (S_0 - C_s)\right)\right]}_{\text{Adsorption and desorption}}$$

Simulator Validation



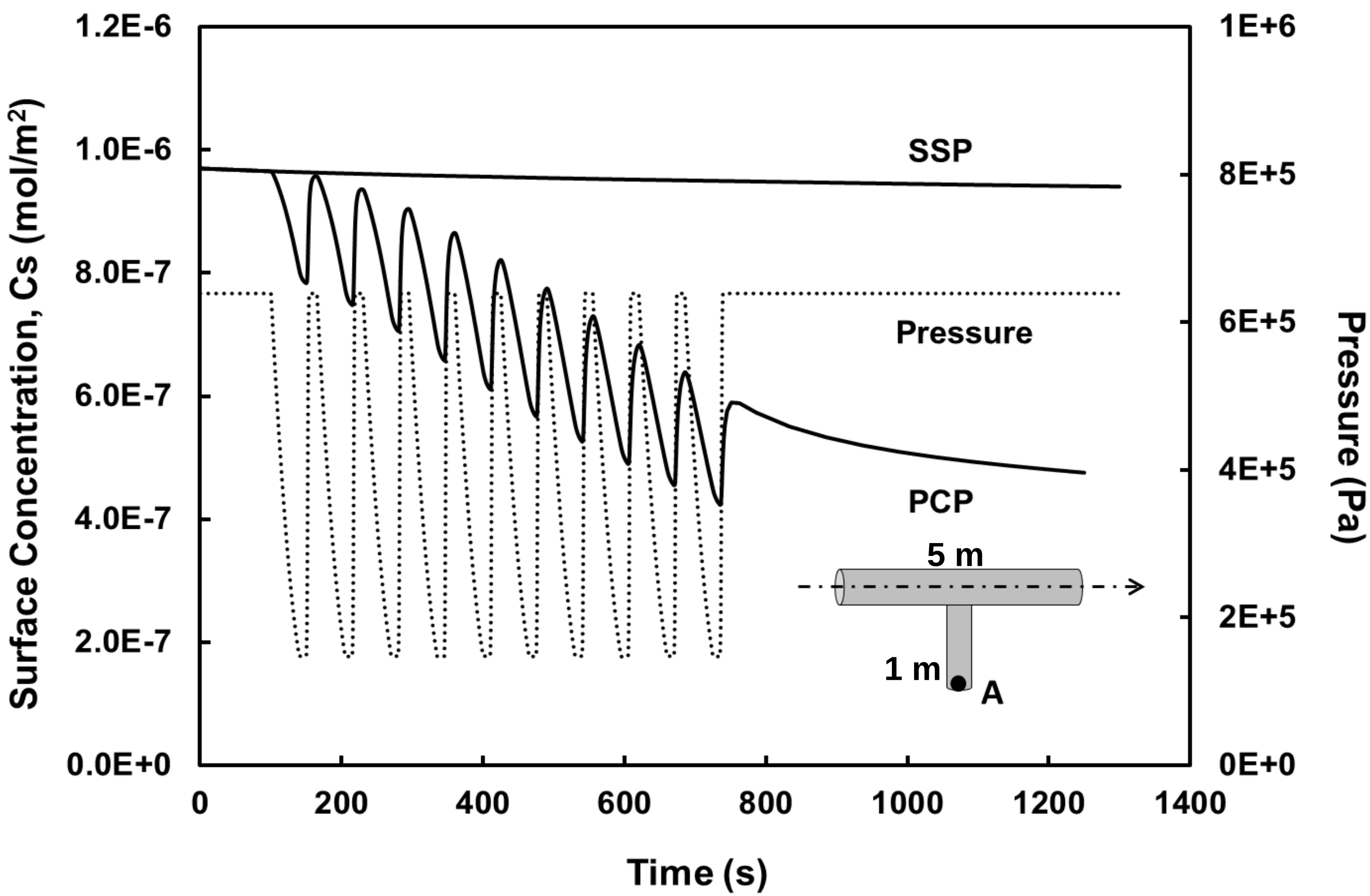
Base Case for PCP-SSP Comparison

Parameters of EPSS distribution line	
Length of Main	2 m
Length of Lateral	1 m
Cavity Width	0.5 m
Cavity Depth	0.5 m
Purge gas concentration	0.2ppb
Surface capacity	1.06E-6 mol/m^2
Lower operating pressure	200000 Pa
Higher operating pressure	640000 Pa
Time in low-pressure stage	100 s
Time in high-pressure stage	50 s
Adsorption rate constant	1000 m^3/(mol*s)
Desorption rate constant	0.01 1/s
Valve loss coefficient	1E8

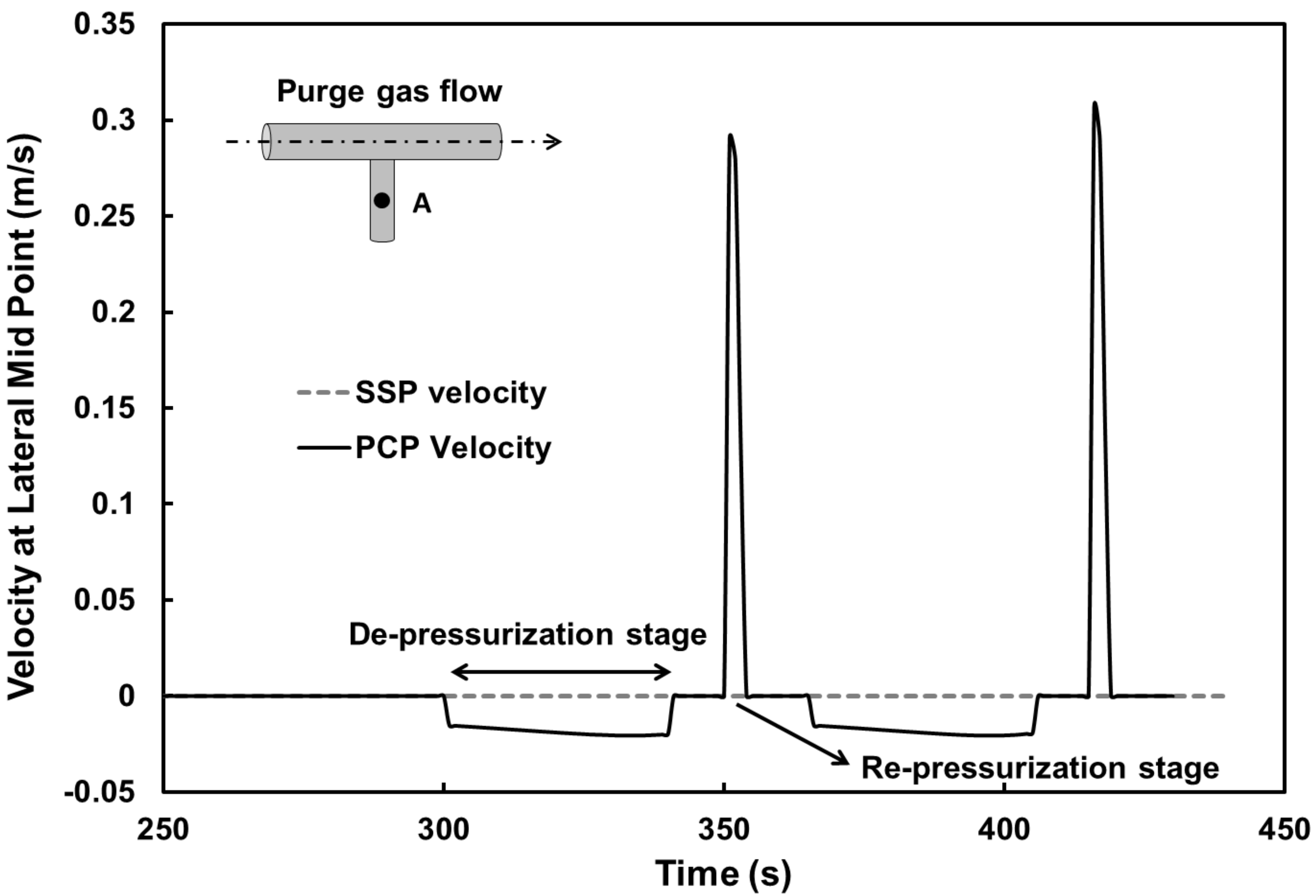


A space in the gas distribution/delivery system or process chamber with little or no convective flow

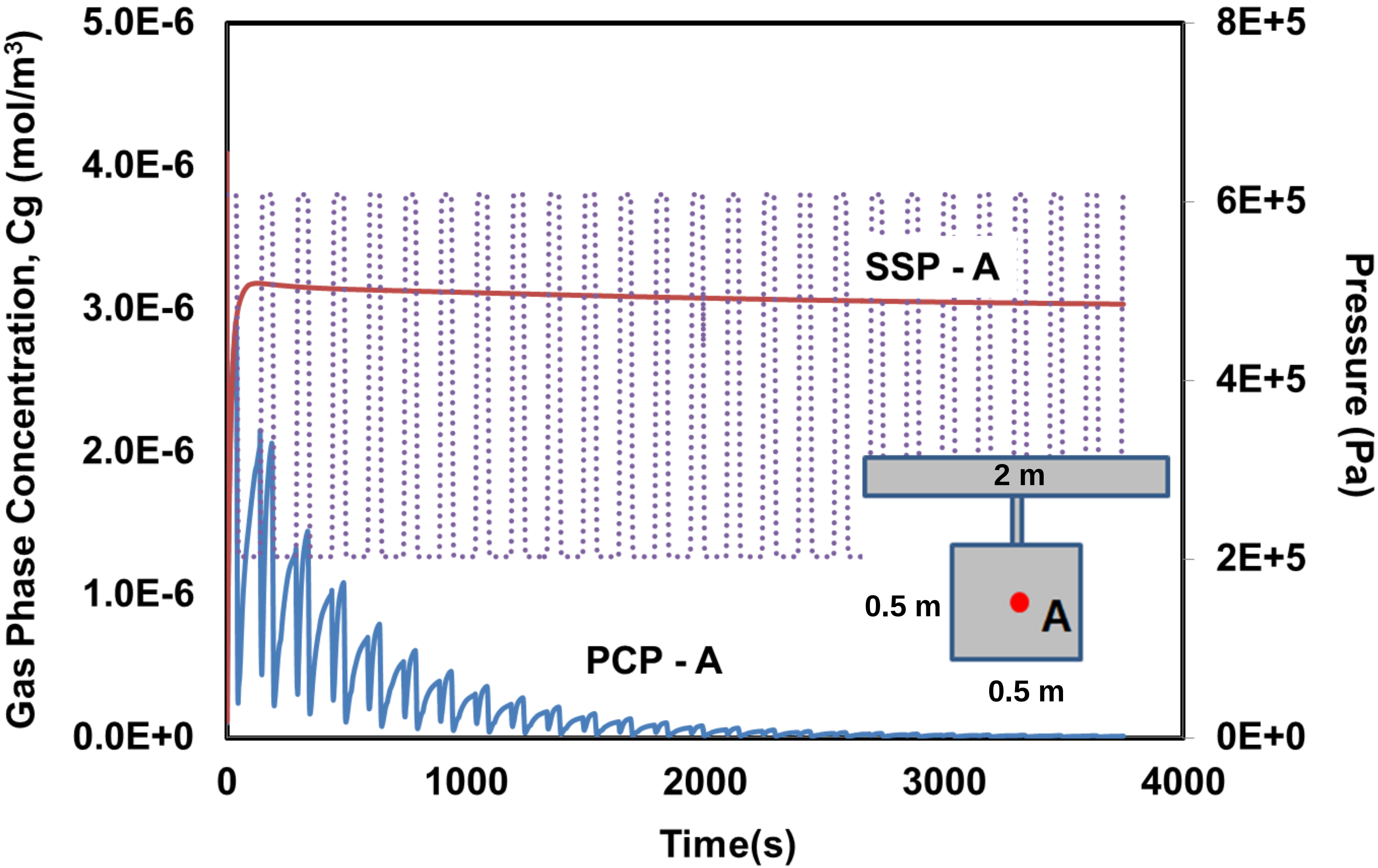
Surface Cleaning of Laterals: PCP vs SSP



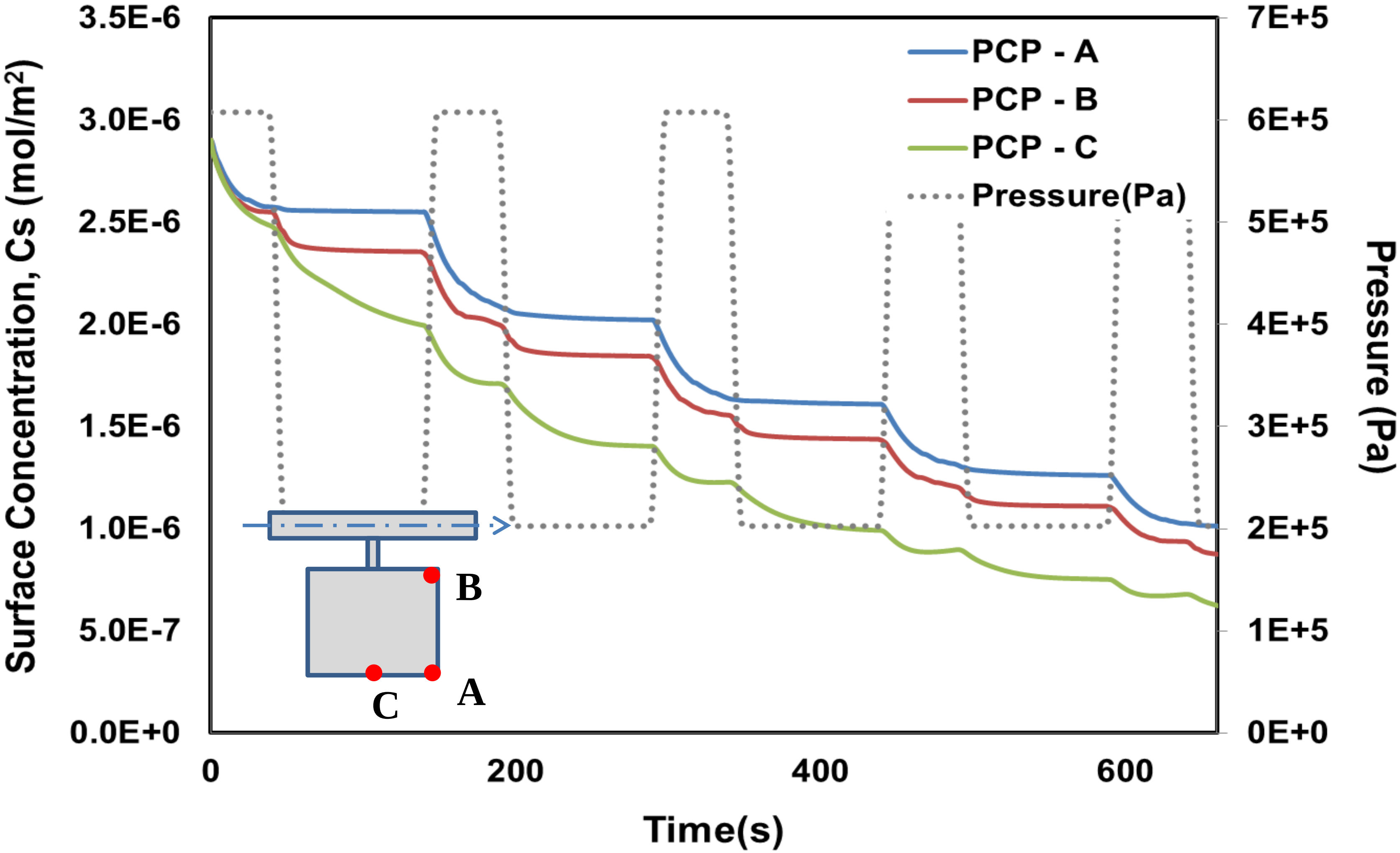
Convection in Laterals: PCP vs SSP



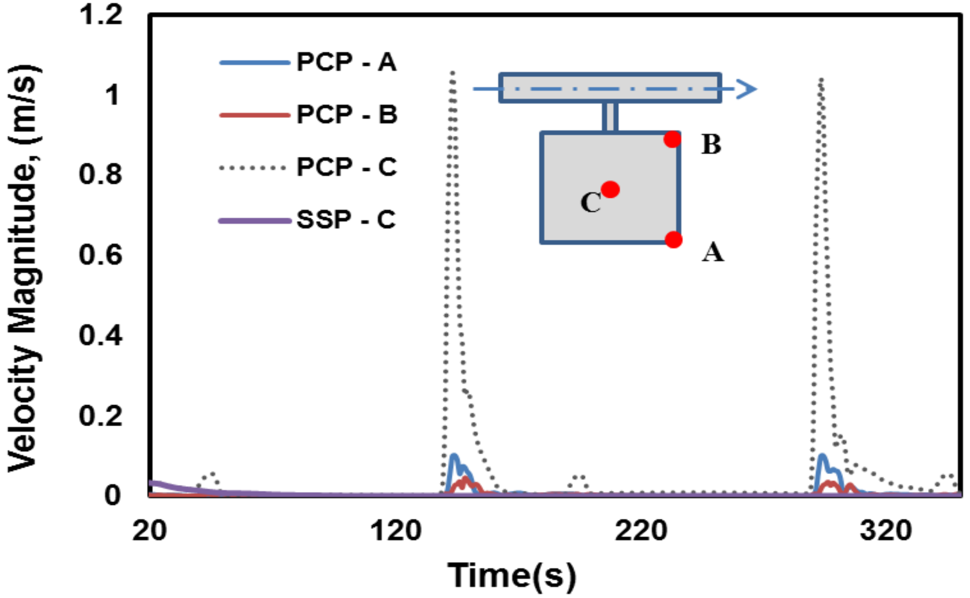
Purging Cavities

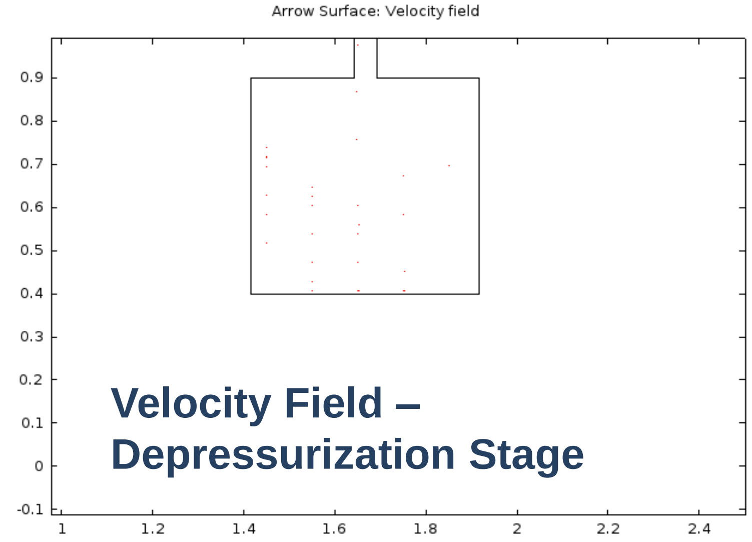


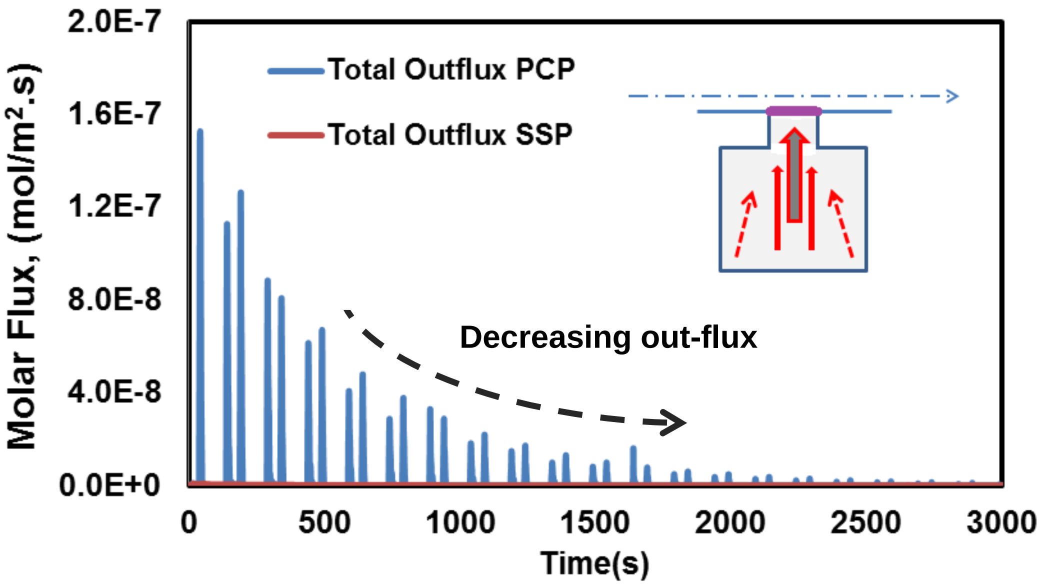
Surface Cleaning in Cavities

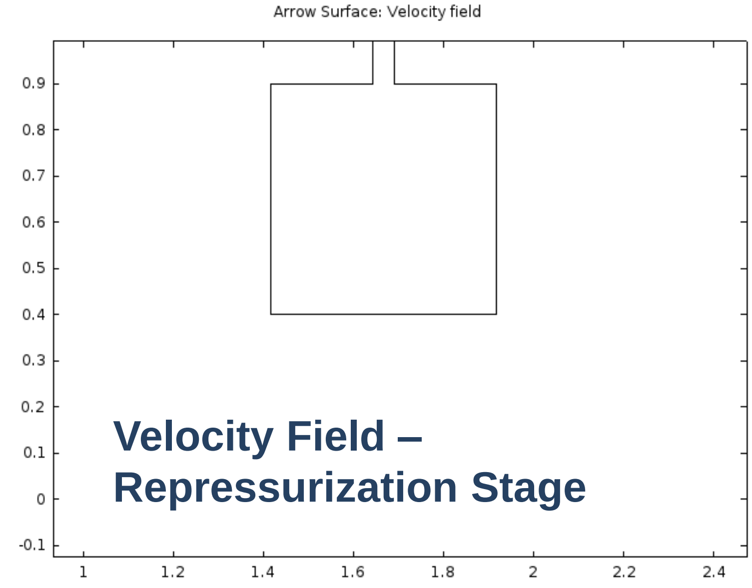


Purge Mechanism

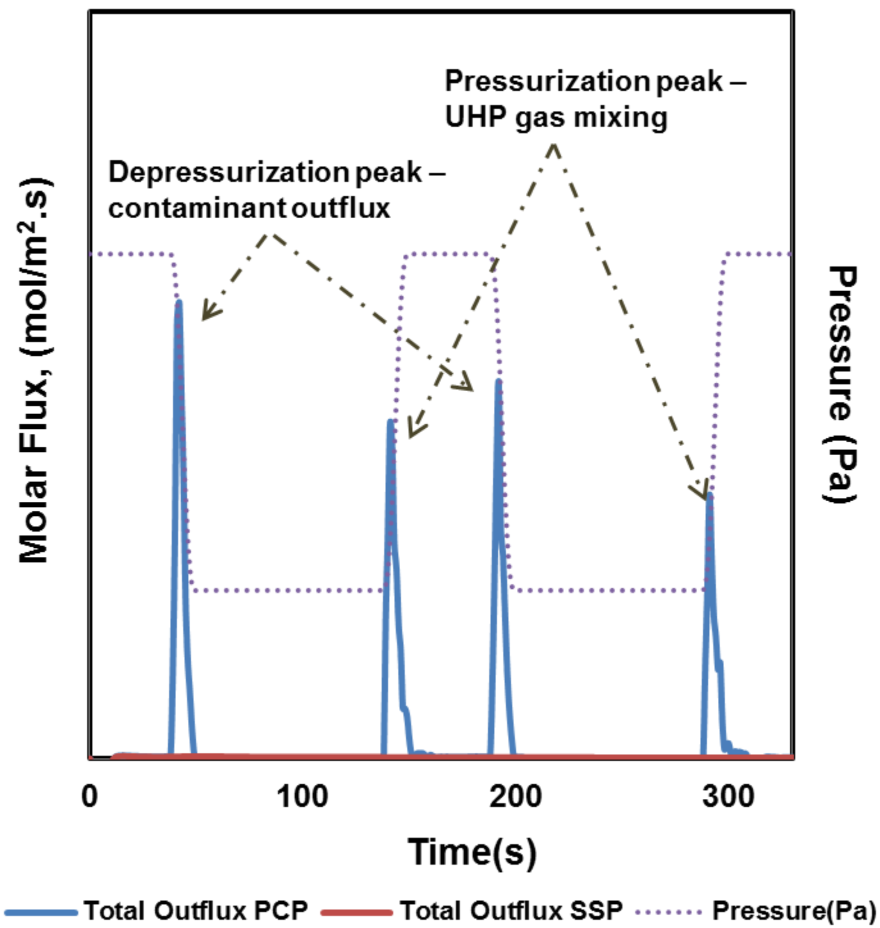


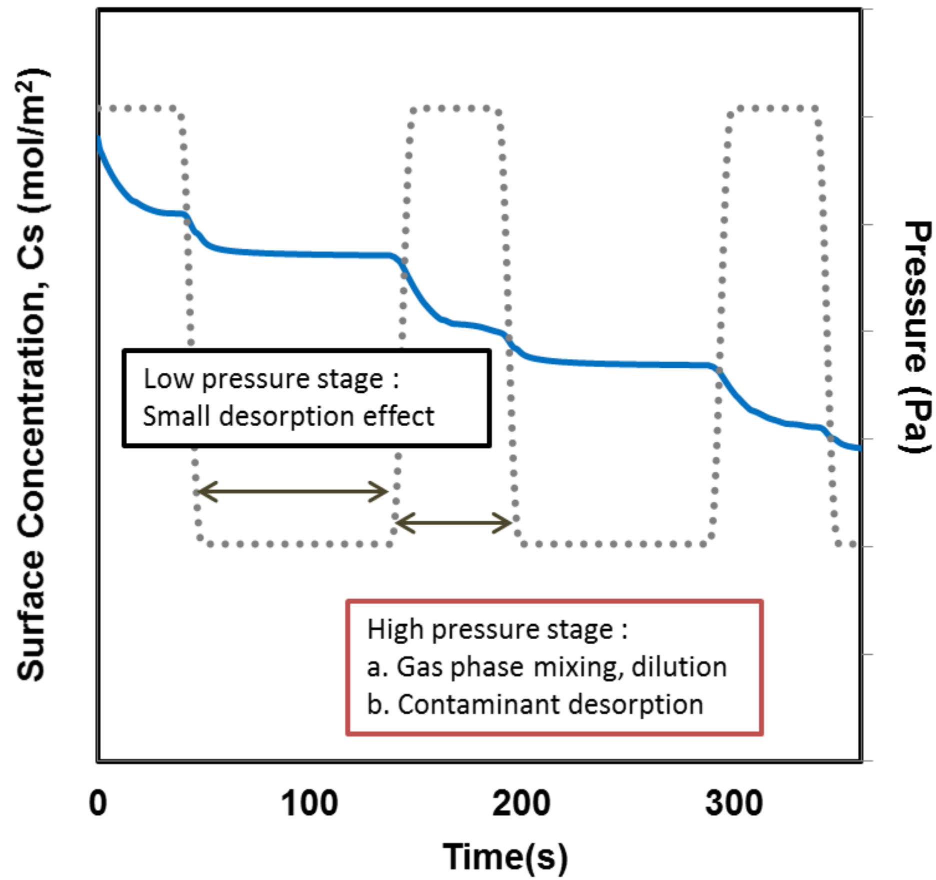






Purge Mechanism

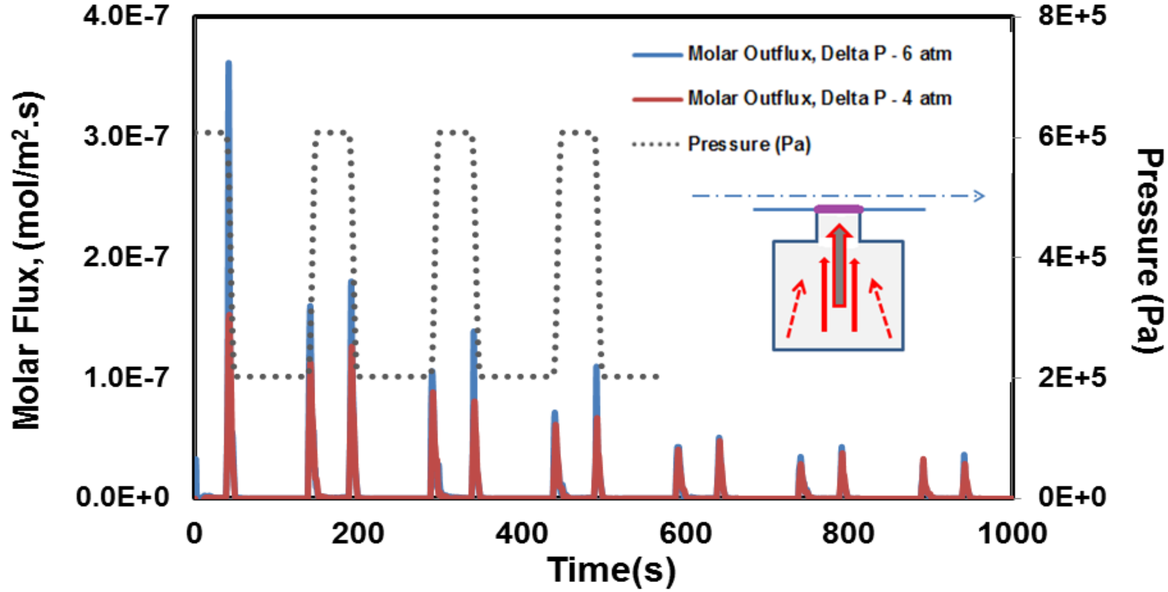


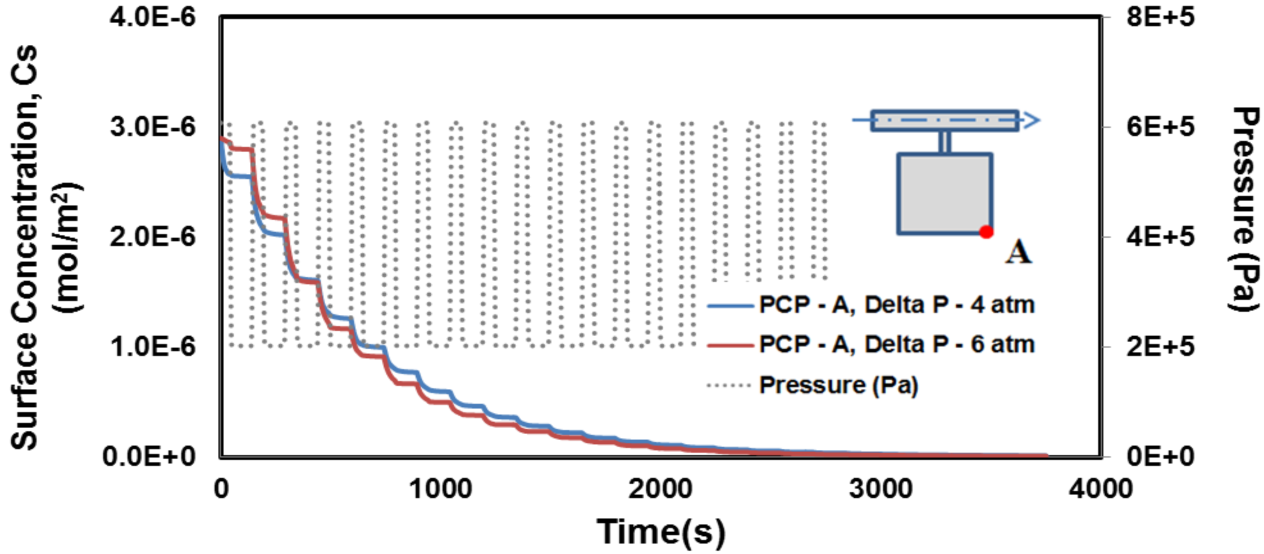


Parametric Studies

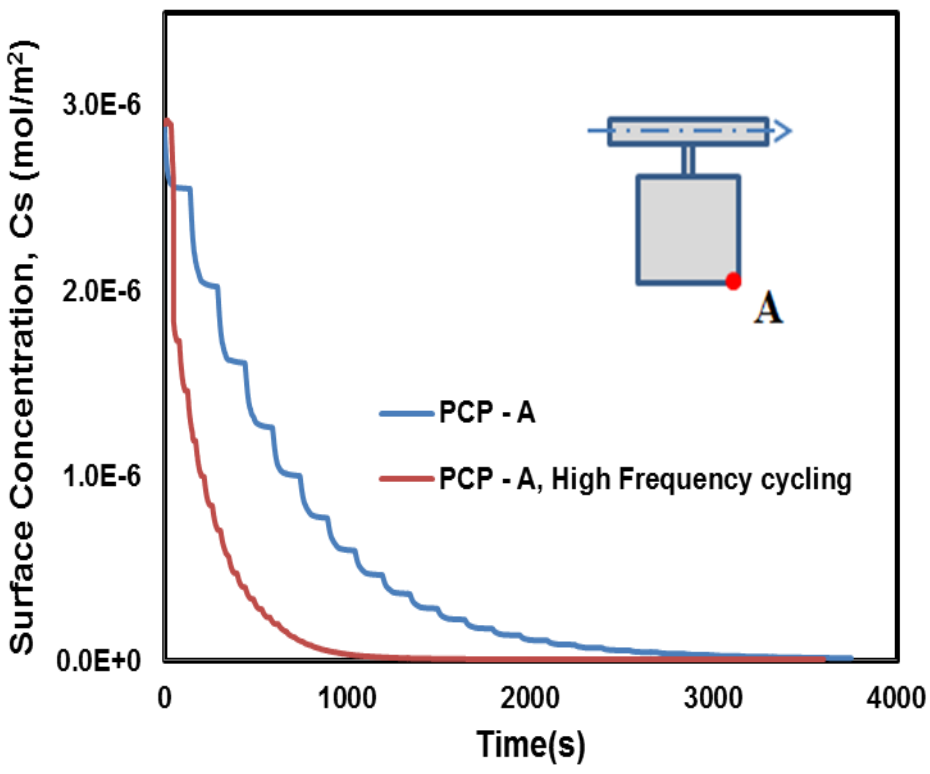
- **Operating pressure range**
- **Cycling frequency**
- **System dimensions**
- **Cavity form**
- **Complex setups**

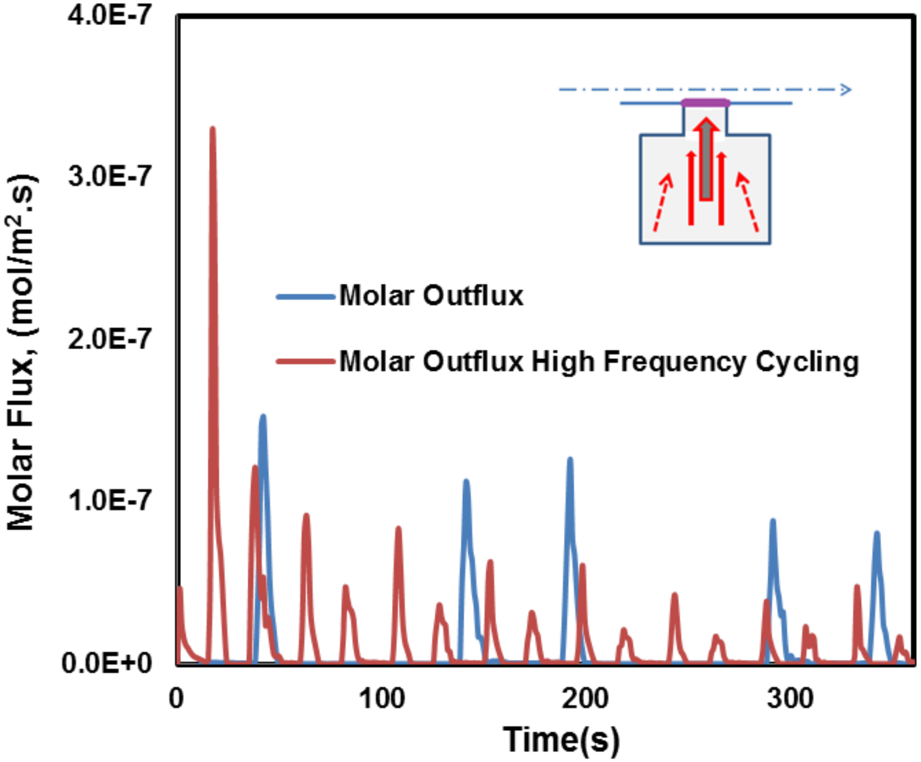
PCP Pressure Cycle Range



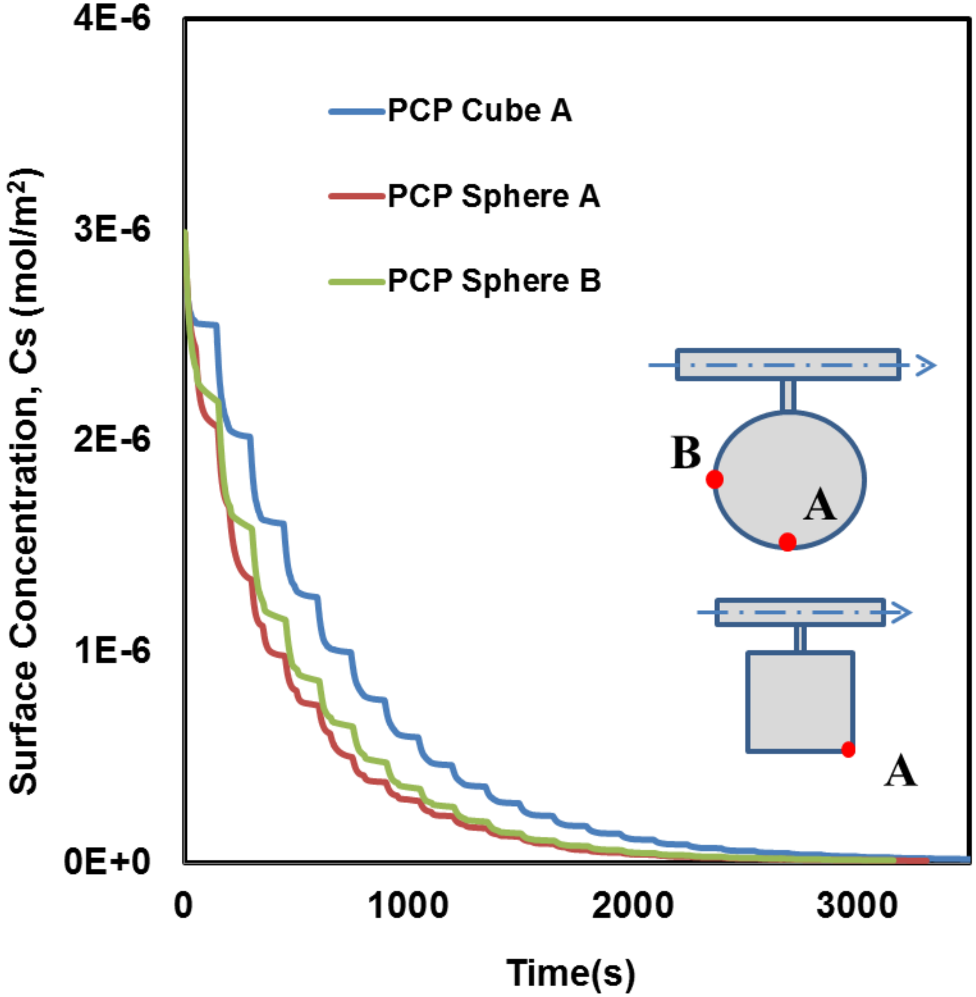


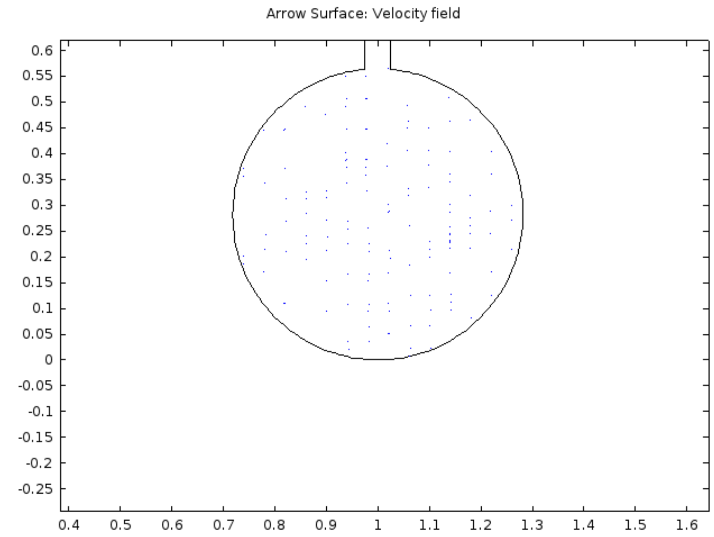
Effect of Cycle Time

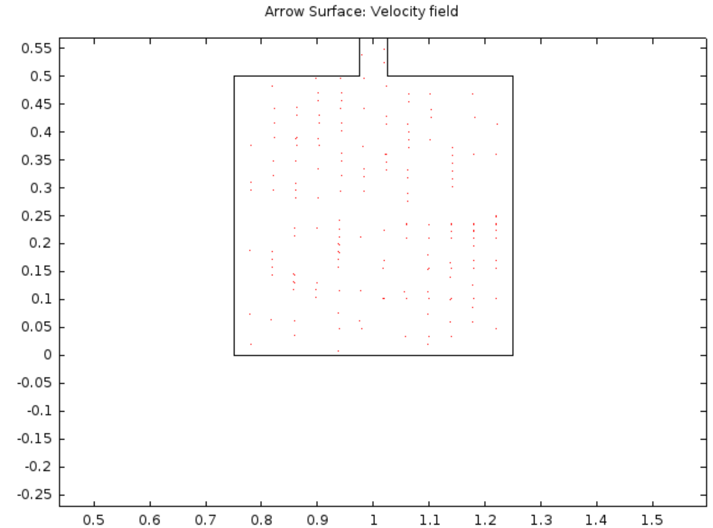




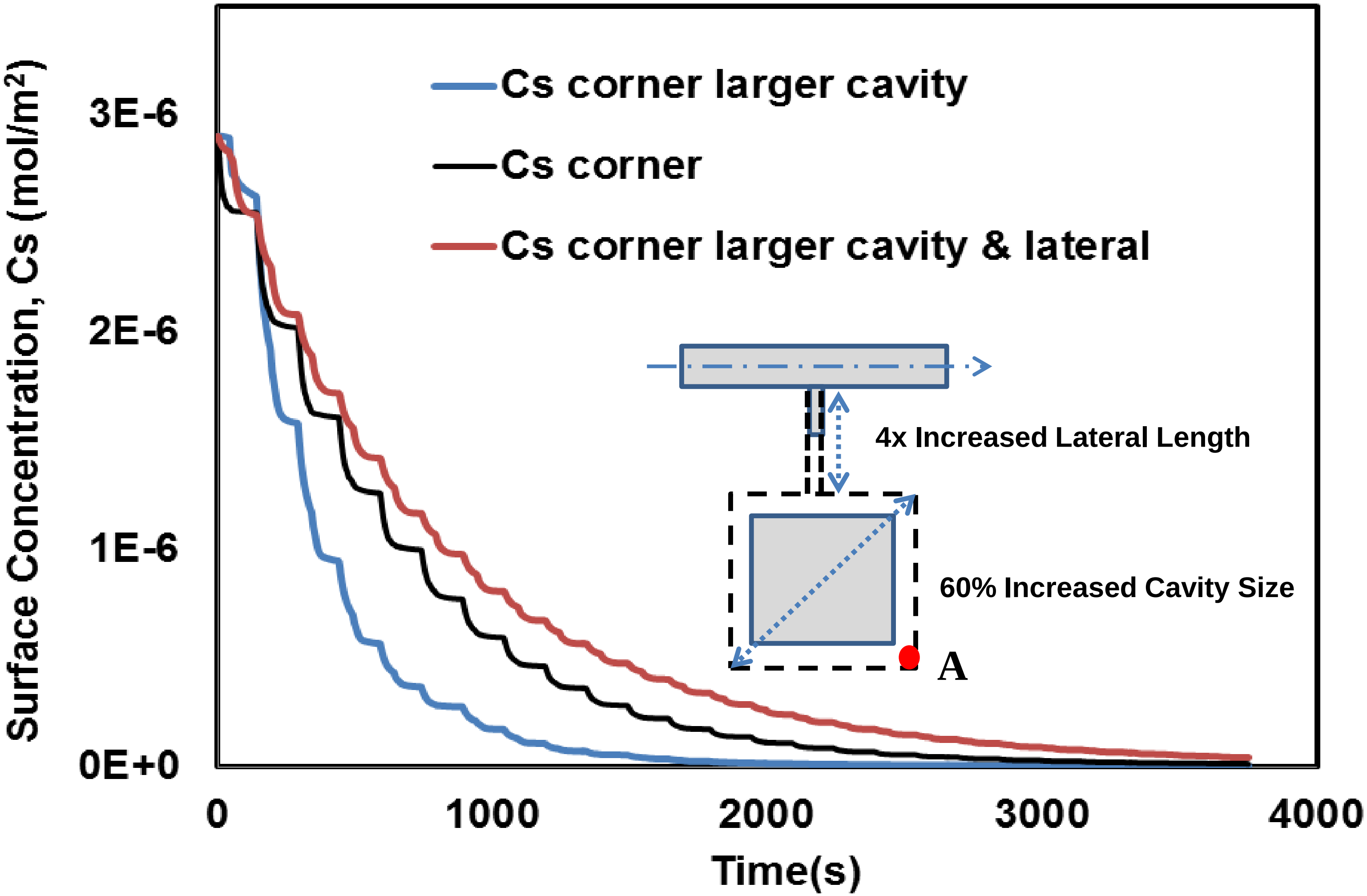
Effect of Cavity Shape



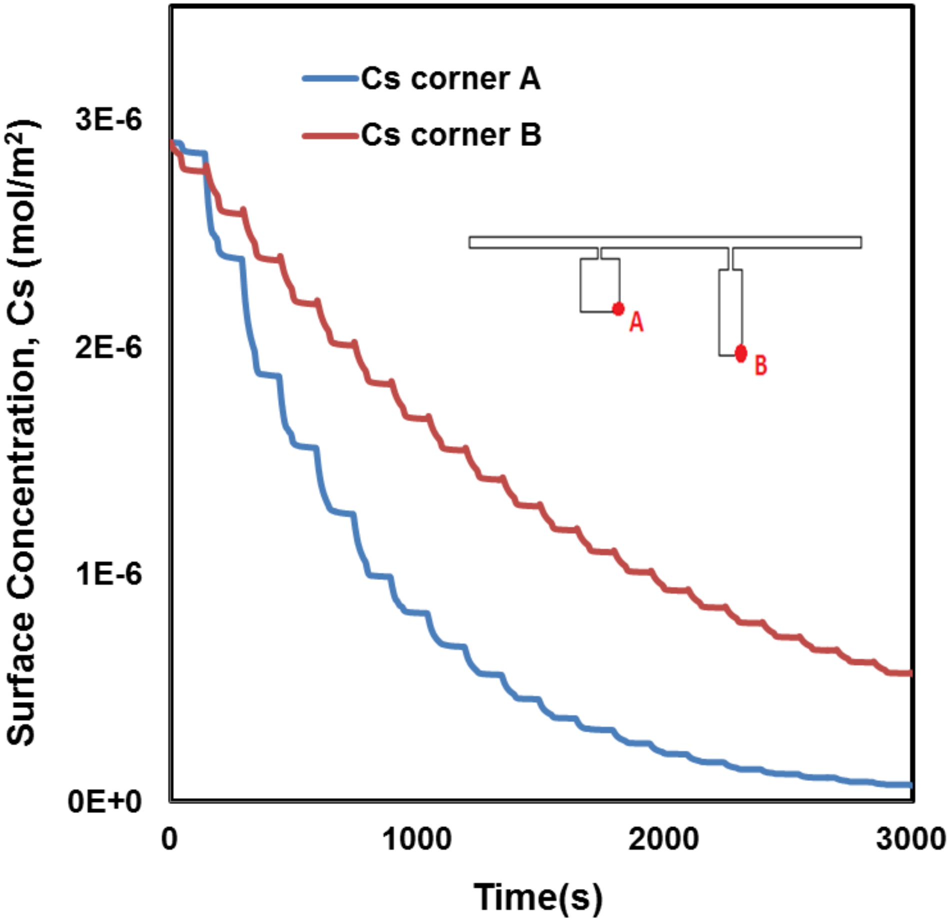


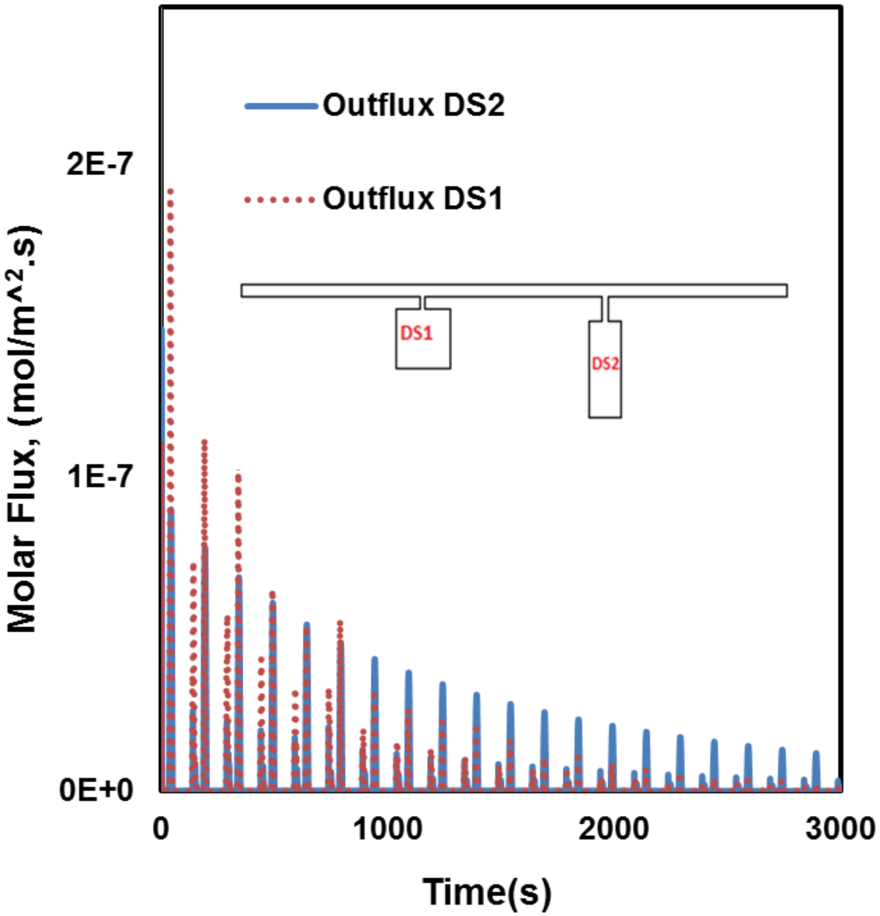


Effect of Cavity Size



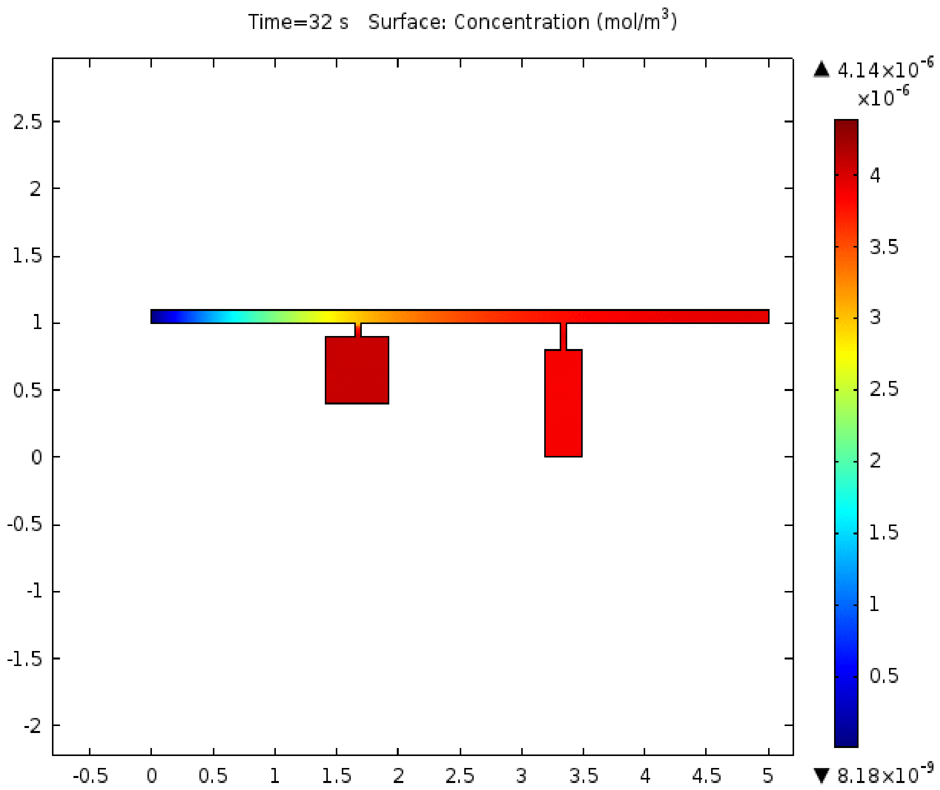
Cavities in Series



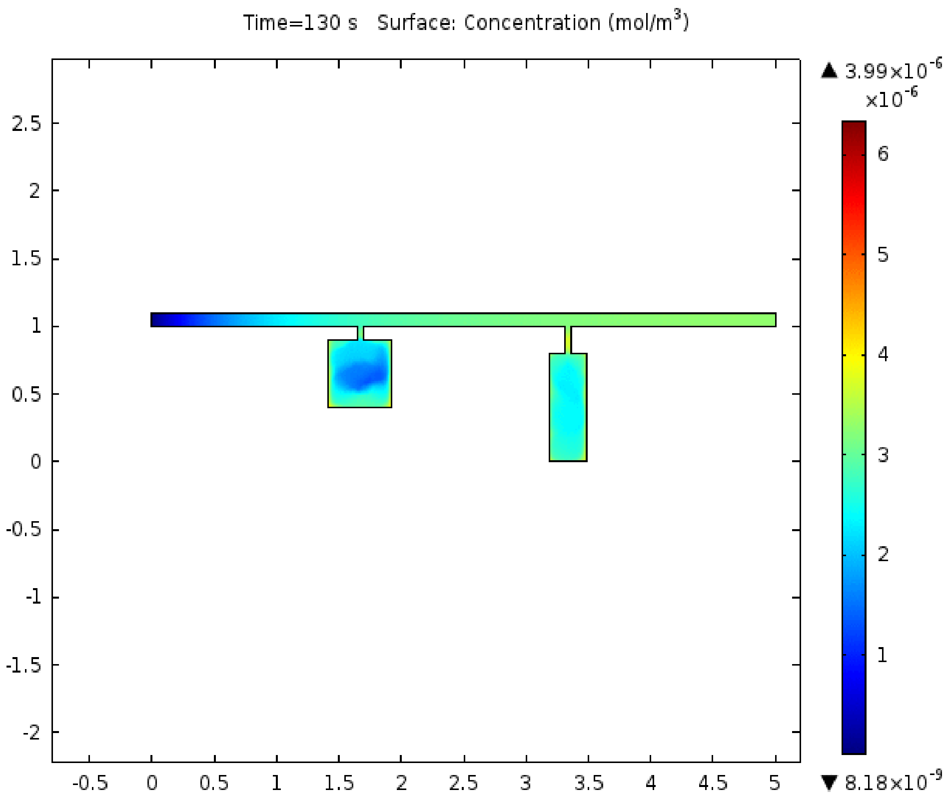


Cavities in Series

Depressurization Stage

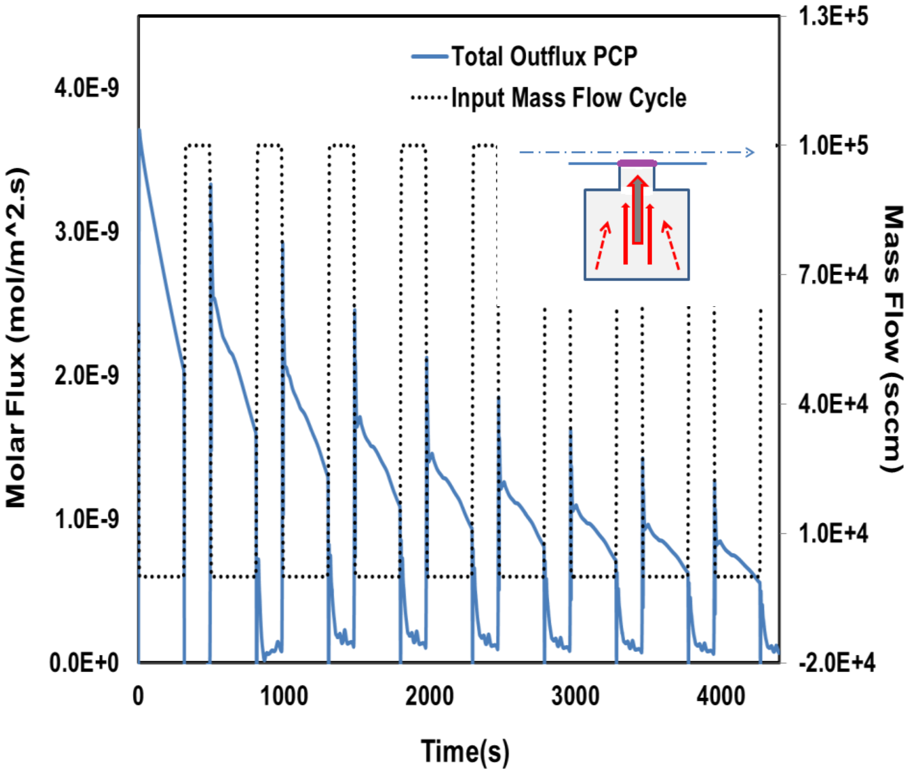


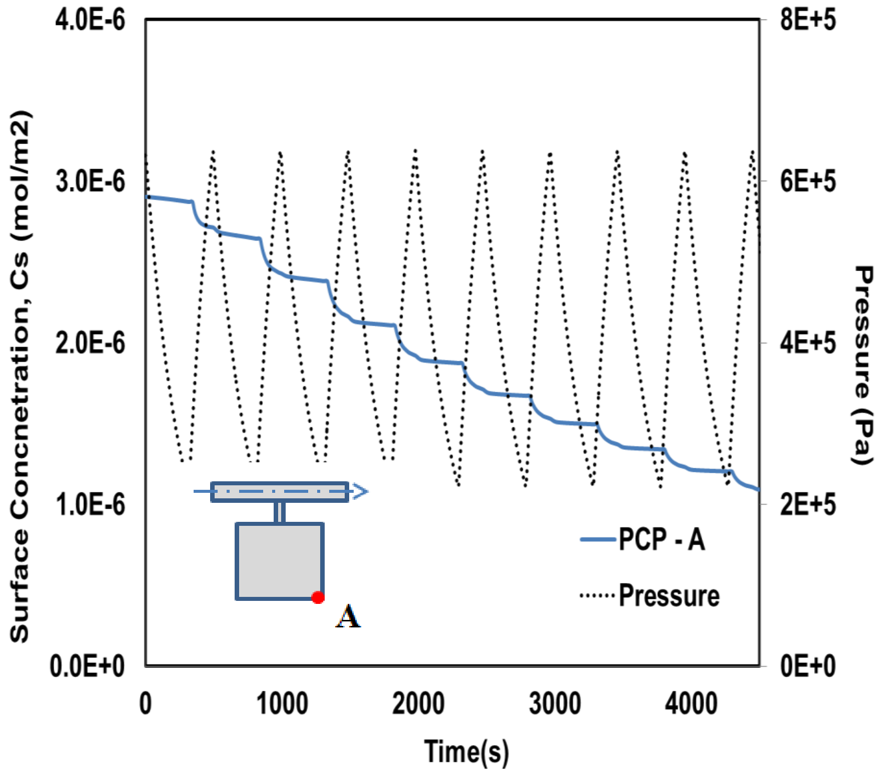
Pressurization Stage



Mass Flow Cycling

An Operator friendly method of implementing PCP in industrial systems





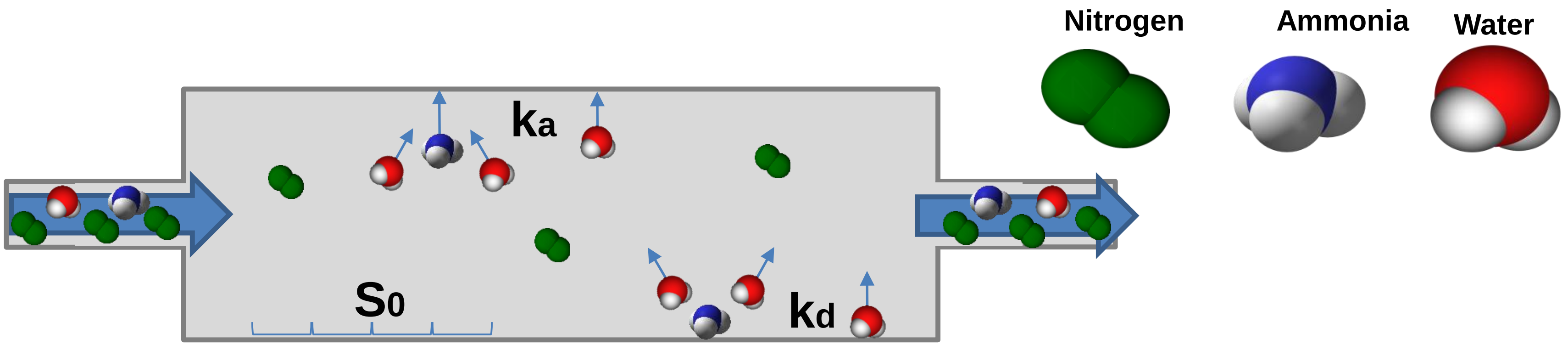
Phase 3: Reducing the Usage of Process Gases

Special Case: Ammonia Usage in Fabs

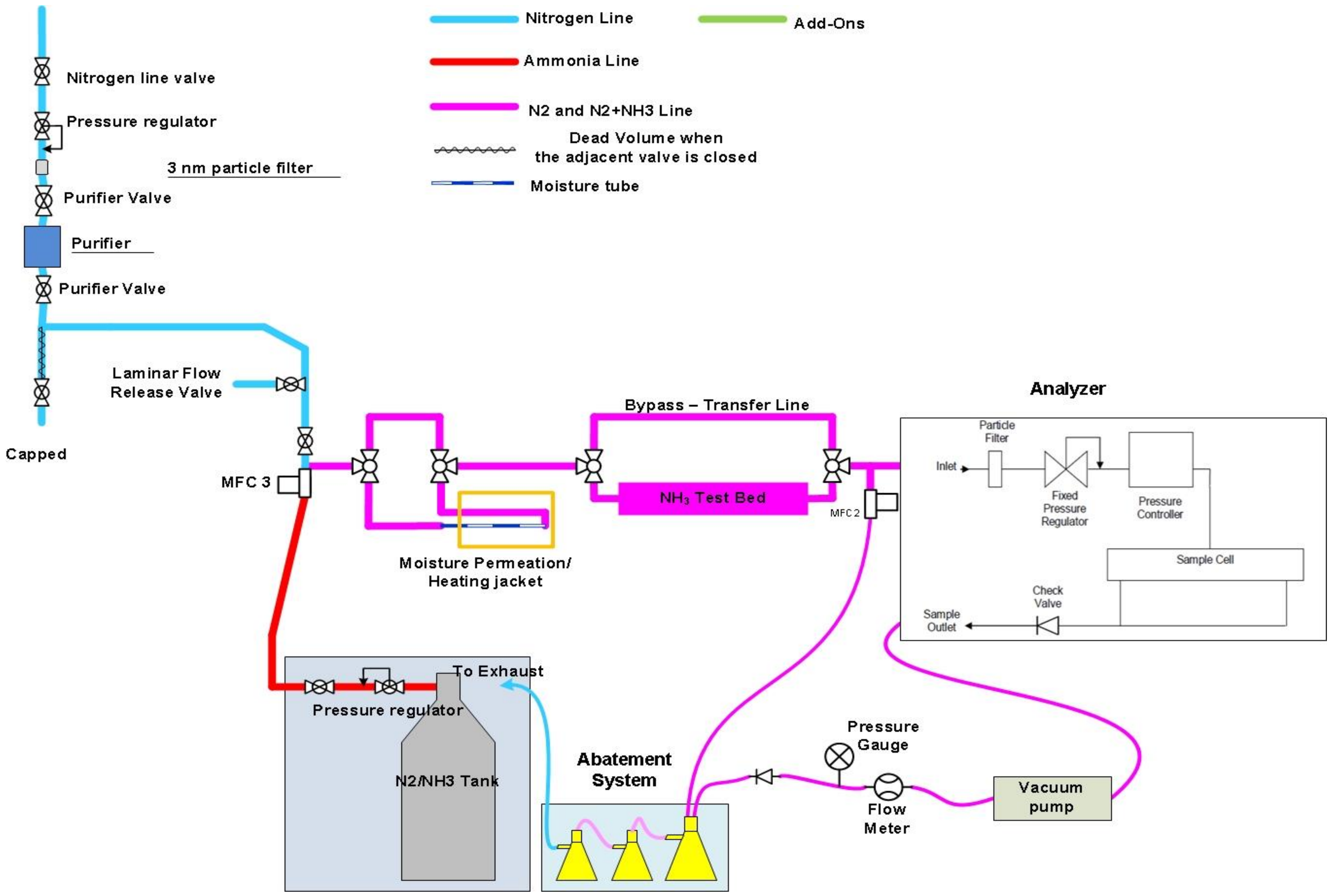
- **Controlling moisture levels in ammonia process streams is a critical factor in ensuring repeatability and performance in associated processes.**
- **Differential evaporation of moisture vs ammonia creates accumulation of moisture with usage**
- **Fluctuation of moisture levels can be noticed with usage, cylinder to cylinder variability and due to diurnal effects**
- **Higher volume of expensive ammonia cylinders are wasted due to the uncontrolled and variable moisture levels required in different processes**

Understanding Moisture - Ammonia in Delivery and Distribution Systems

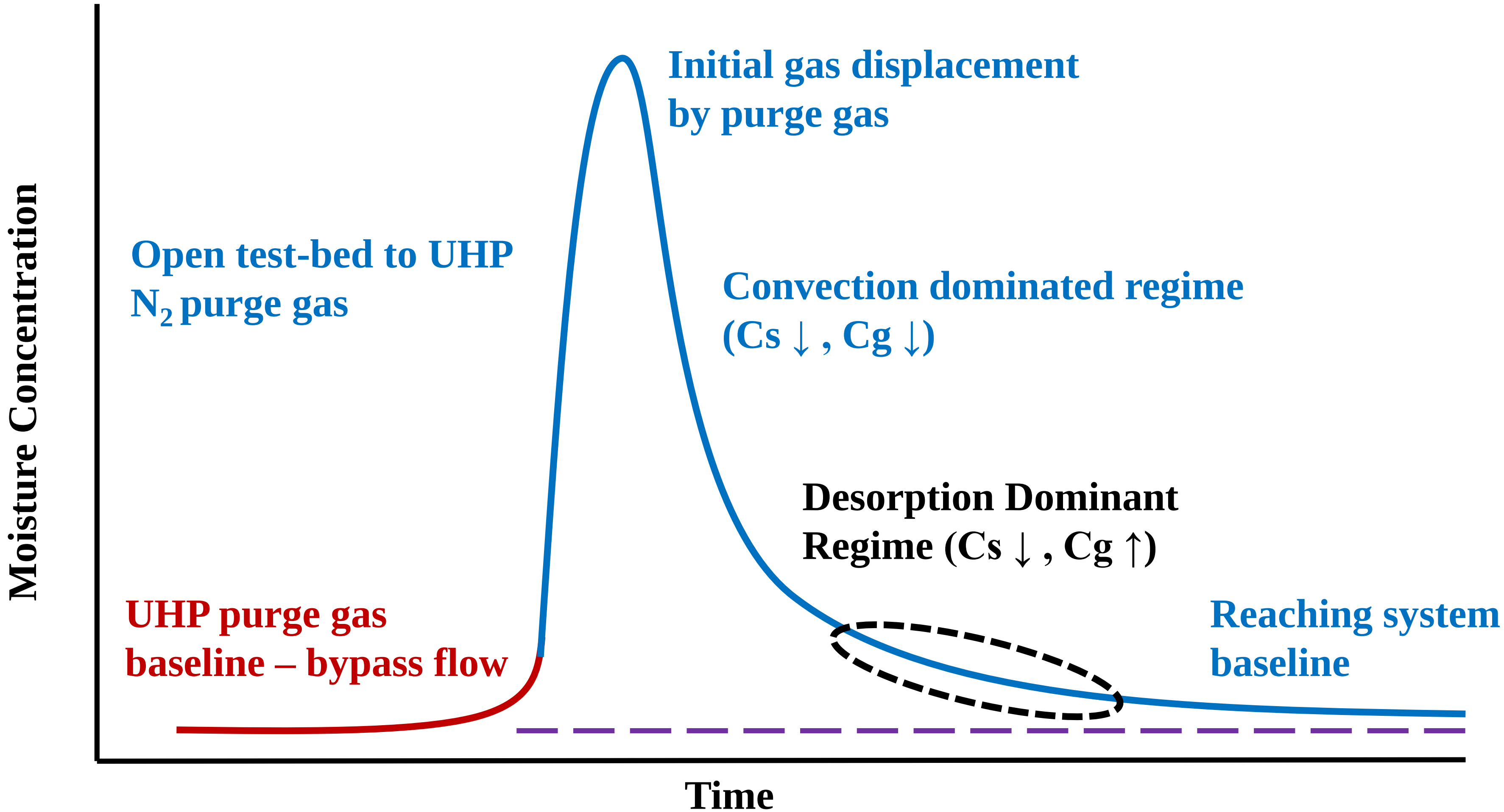
- Multicomponent adsorption/desorption tests to determine system kinetics
- Challenge with varying moisture, ammonia concentrations, flow rates to estimate rate parameters
- Build and validate a process simulator for further studies and application to new methods in reducing ammonia usage.



Experimental Setup



Finding the Process Parameters by Dynamic Adsorption/Desorption Study



Multi-Component Kinetic Studies

Gas-phase component mass balance

$$\frac{dC_{gi}}{dt} = \frac{Q}{V}\left(C_{g,in} - C_{gi}\right) + \frac{4}{d}\left(k_{di}C_{si} - k_{ai}C_{gi}(S_{0i} - C_{si})\right)$$

$where\ \ i = H_2O\ in\ N_2\ or\ H_2O\ in\ NH_3$

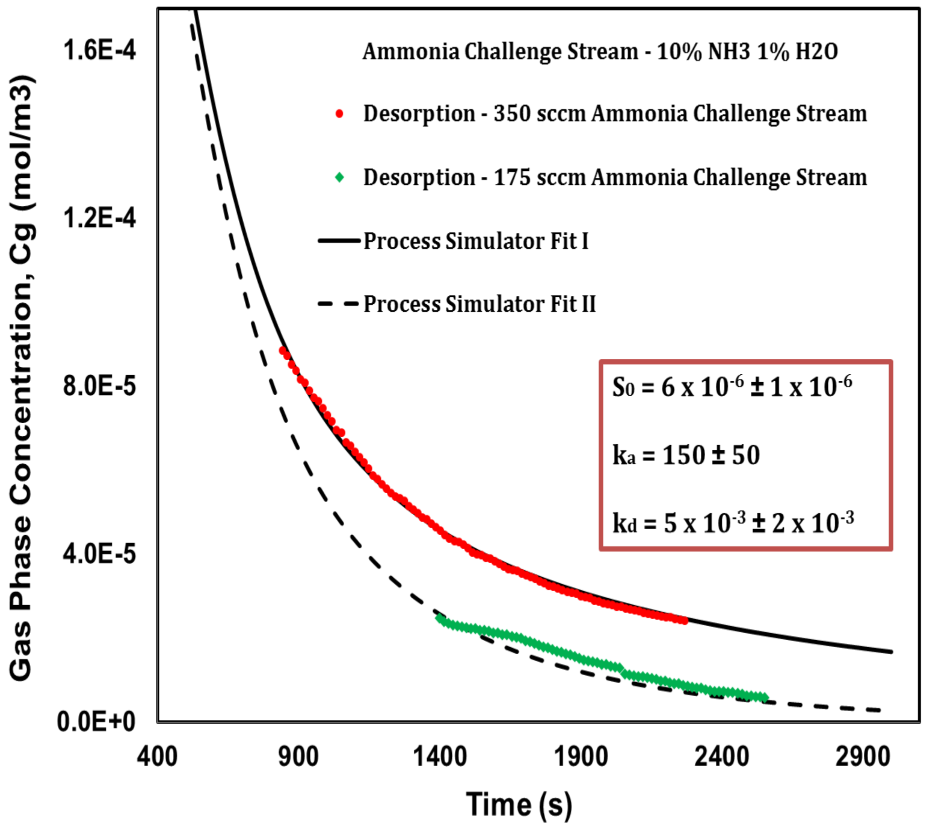
Surface component mass balance

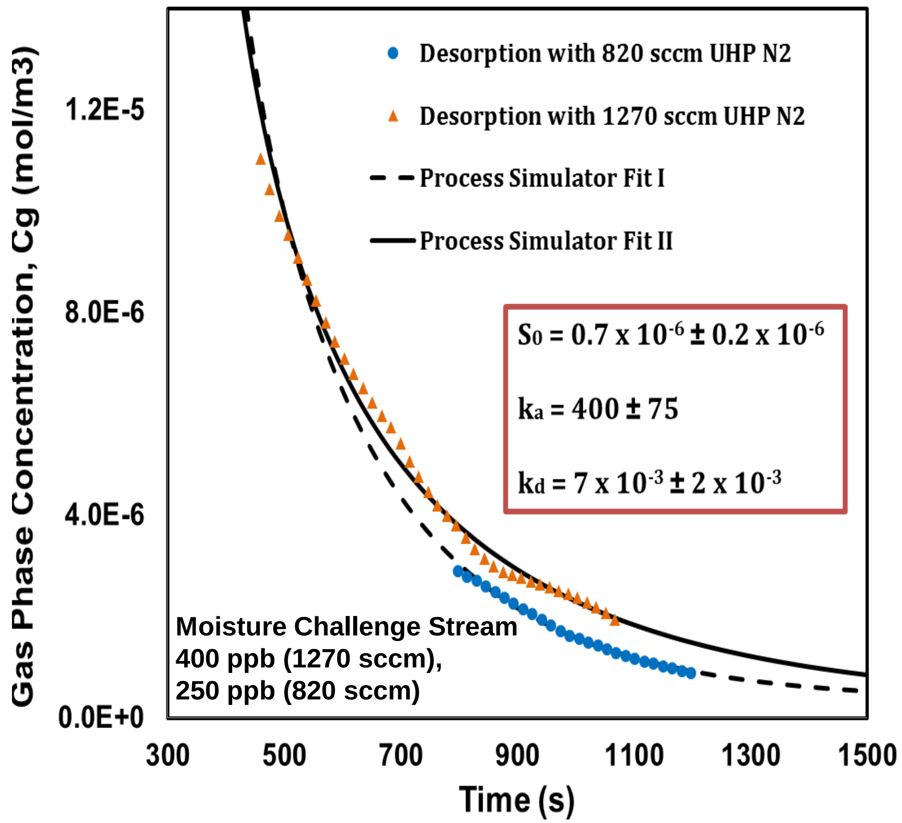
$$\frac{dC_{si}}{dt} = k_{ai}C_{gi}(S_{0i} - C_{si}) - k_{di}C_{si}$$

Kinetic parameters

- k_{ai} - Adsorption rate constant of component $\boldsymbol{i}$
- k_{di} - Desorption rate constant of component $\boldsymbol{i}$
- S_{0i} - Total number of surface sites available for component $\boldsymbol{i}$

Multicomponent Kinetic Parameters





Summary and Conclusions

- The proposed pressure cycle purge (PCP) approach, when designed and implemented properly for a system, has a major environmental and process benefits:
  - Reduces the usage of expensive UHP purge gases
  - Reduces the volume of waste streams
  - Reduces operating cost
  - Improves the reliability of gas quality at the POU
  - Minimizes the down time required for purging delivery lines, components, and process tools.

- The process simulator developed in this study is an effective and user-friendly tool for the design and implementation of PCP in a system.

Future Plan

- Continue working with Intel on methods to reduce the usage of process gases, purge gases, and expensive purification materials/methods by controlling the transient introduction of key impurities through adsorption/desorption, back diffusion, and other interactions in UHP gas delivery systems.

- The first case study selected for process gas use reduction is on ammonia usage and its moisture control.

- This customized project is open to other SRC members who like to join the collaboration.

Industrial Interactions

- **Technology transfer and some implementation of results at Intel fabs have already taken place.**
- **Process simulator was requested by and sent to AMAT**
- **Other opportunities for tech transfer, case studies, and applications are invited.**

Publications and Presentations

- **Jivaan Kishore, Roy Dittler, Carl Geisert, Farhang Shadman. "Pressure Cycling for Purging of Dead Spaces in High-Purity Gas Delivery Systems." submitted and in review, *AIChE Journal*, February 2015.**

- **Roy Dittler, Jivaan Kishore, Carl Geisert, Farhang Shadman. "Contamination of Ultra-High-Purity (UHP) Gas Distribution Systems by Back Diffusion of Impurities." *Journal of the IEST* 57 (1), 2014.**

- **Hao Wang, H. and Shadman, F. "Effect of Particle Size on the Adsorption and Desorption Properties of Oxide Nanoparticles" *AIChE Journal 59(5), 1502 (2013)*.**

Acknowledgements

- **Carl Geisert (Intel)**
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