Novel Methods for Reducing UHP Gas Usage in Fabs

Customized Project; Sponsored by Intel

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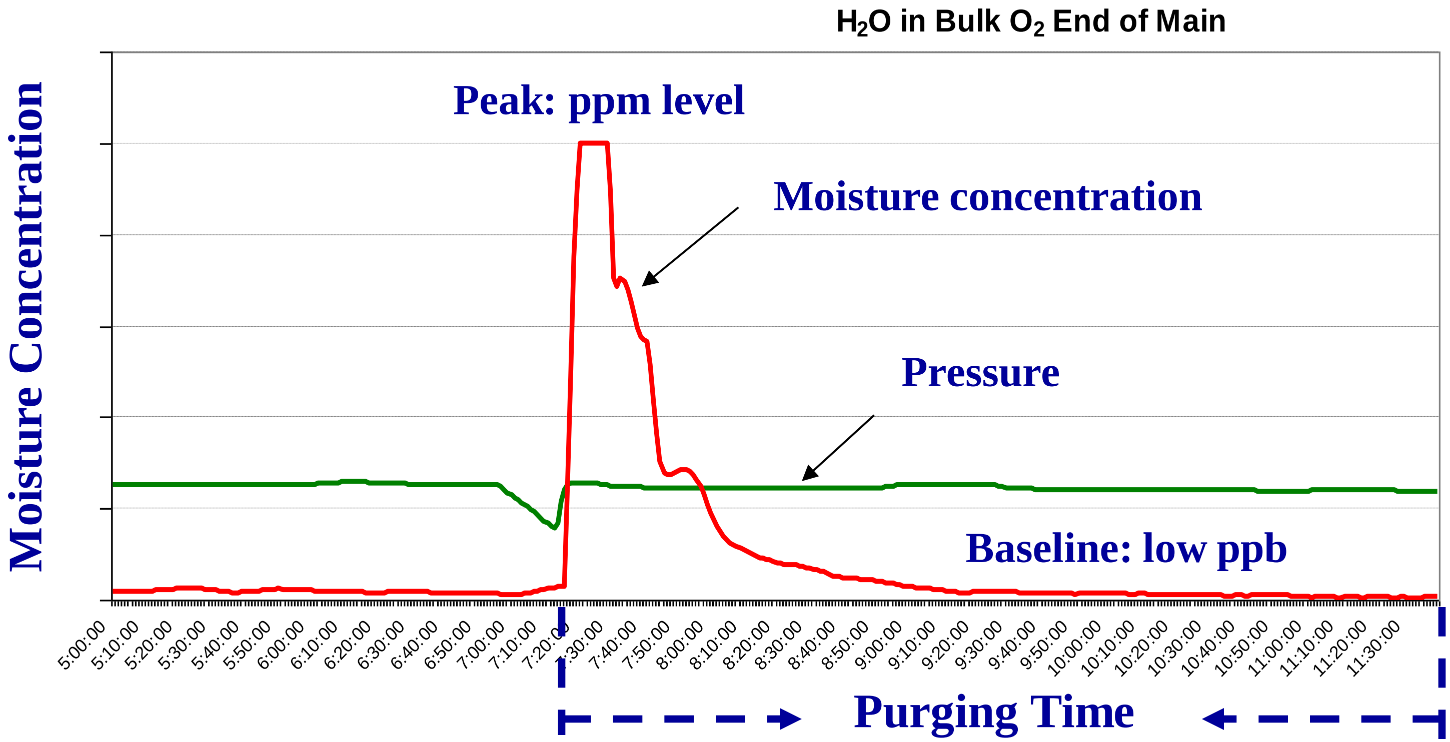
Other Researchers:

- **Jun Yan: Ph.D. research assistant professor, Chemical and Environmental Engineering, UA**

Moisture Contamination & Dry-down



a few hours ~ several weeks

Fab closure due to gas distribution systems failure may cause revenue loss somewhere between $5M and $15 M/day

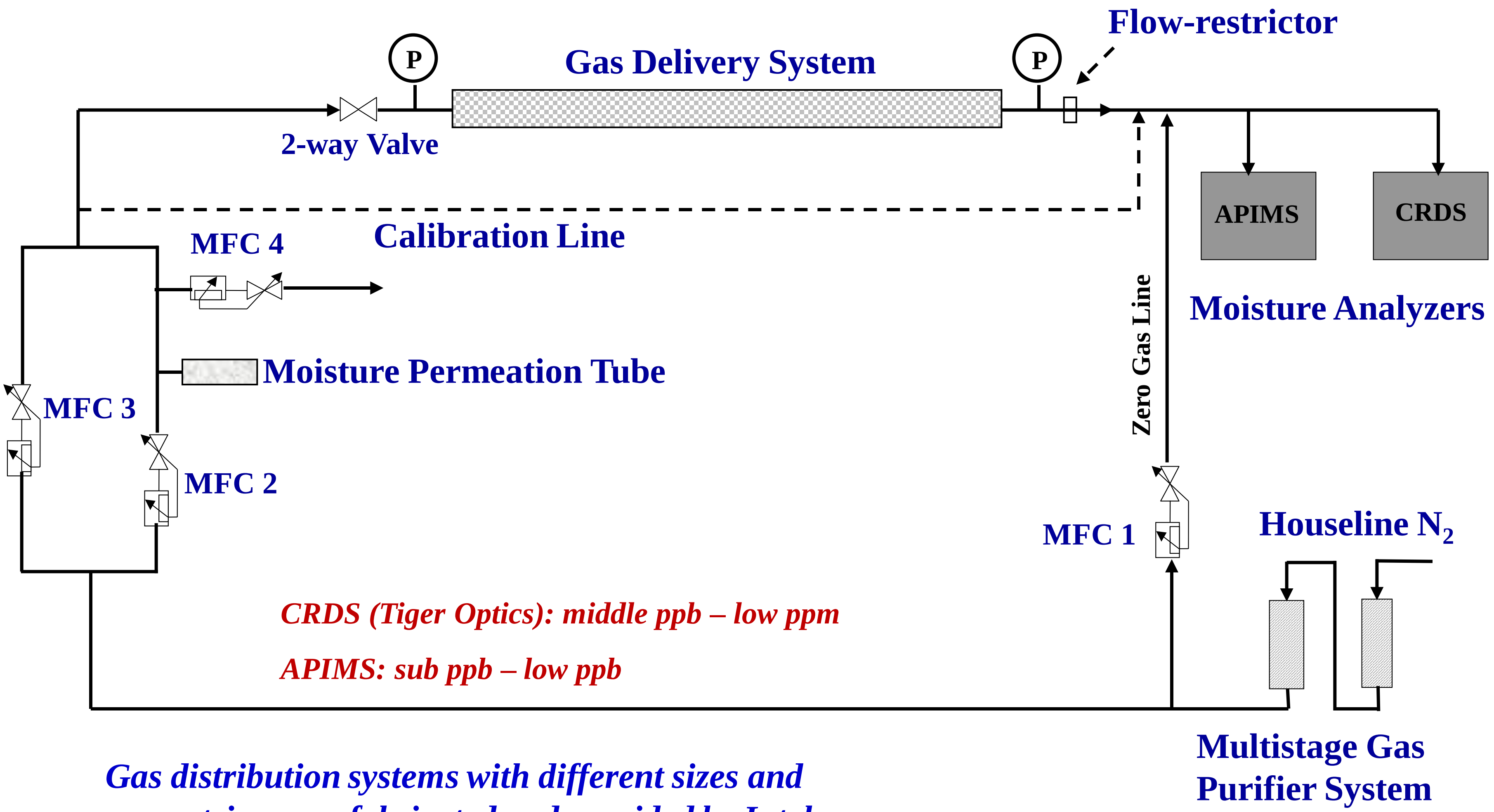
Objectives

- Develop tools and techniques for analysis of contamination distribution and removal in ultra-pure gas distribution systems.
- Develop and validate a user-friendly process simulator suitable for field application to minimize purge time and gas usage during system start up, system recovery, or during the operation of gas distribution systems.

ESH Impact

- Contamination of gas distribution systems during operation or at start-up is a major source of wasted time, materials, and energy.
- Significant reduction in purging time and purging gas usage can be accomplished by newly developed cyclic purge procedures.

Experimental Testbed

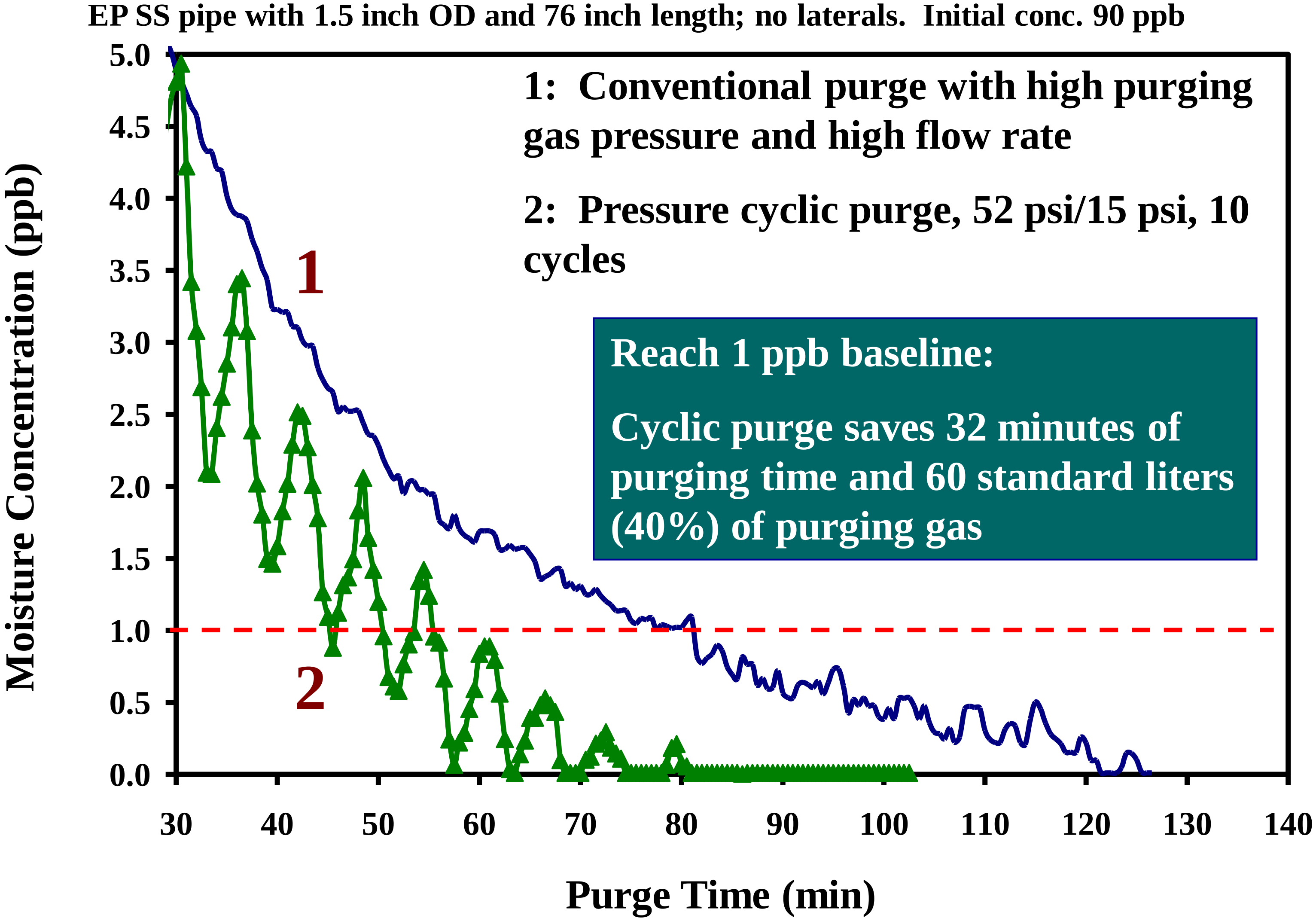


CRDS (Tiger Optics): middle ppb – low ppm

APIMS: sub ppb – low ppb

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

Comparison of Pressure Cyclic Purge with Conventional Purge

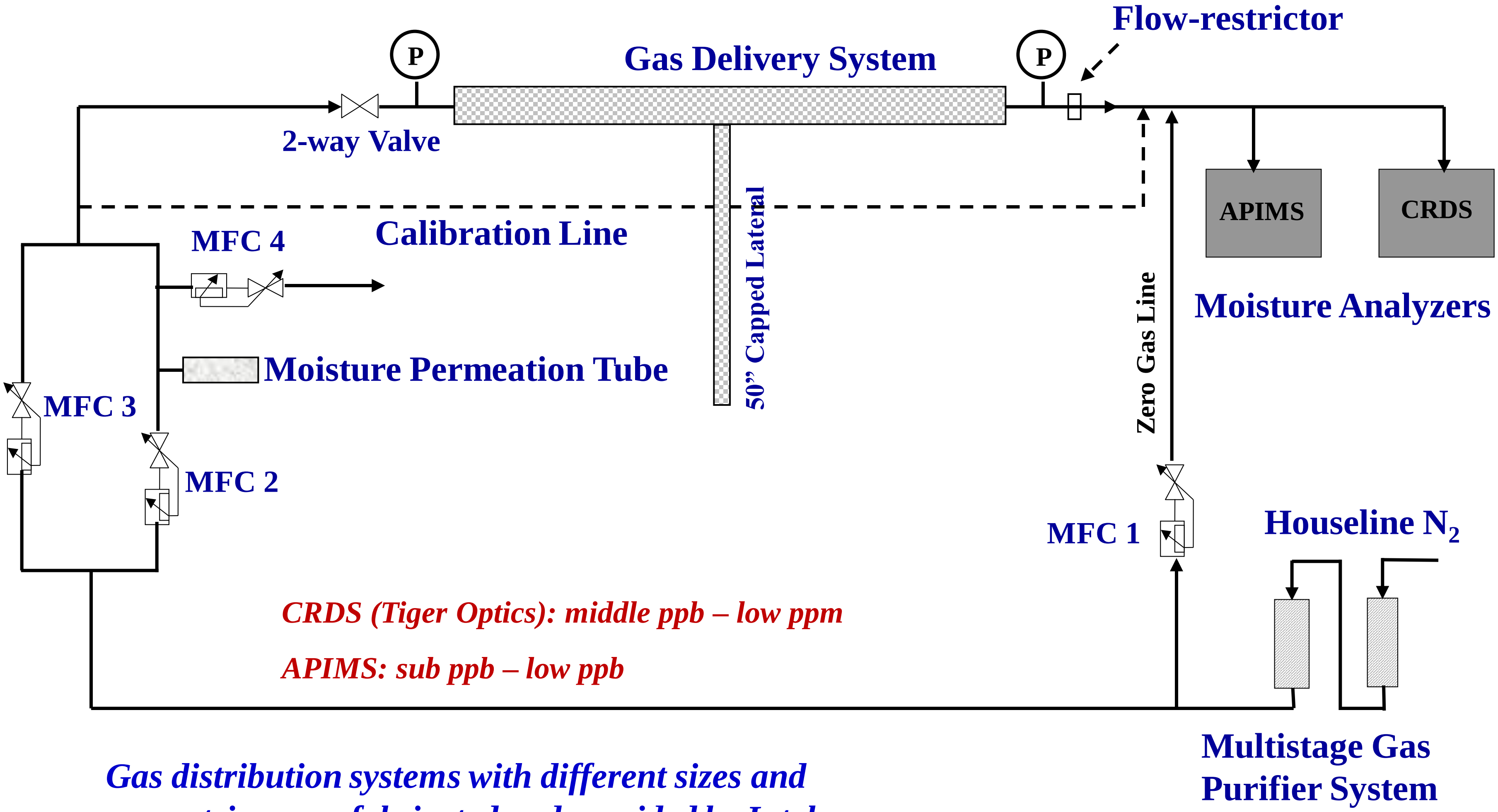


Reach 1 ppb baseline:

Cyclic purge saves 32 minutes of purging time and 60 standard liters (40%) of purging gas

Experimental Testbed

Laterals Added to the Main Line



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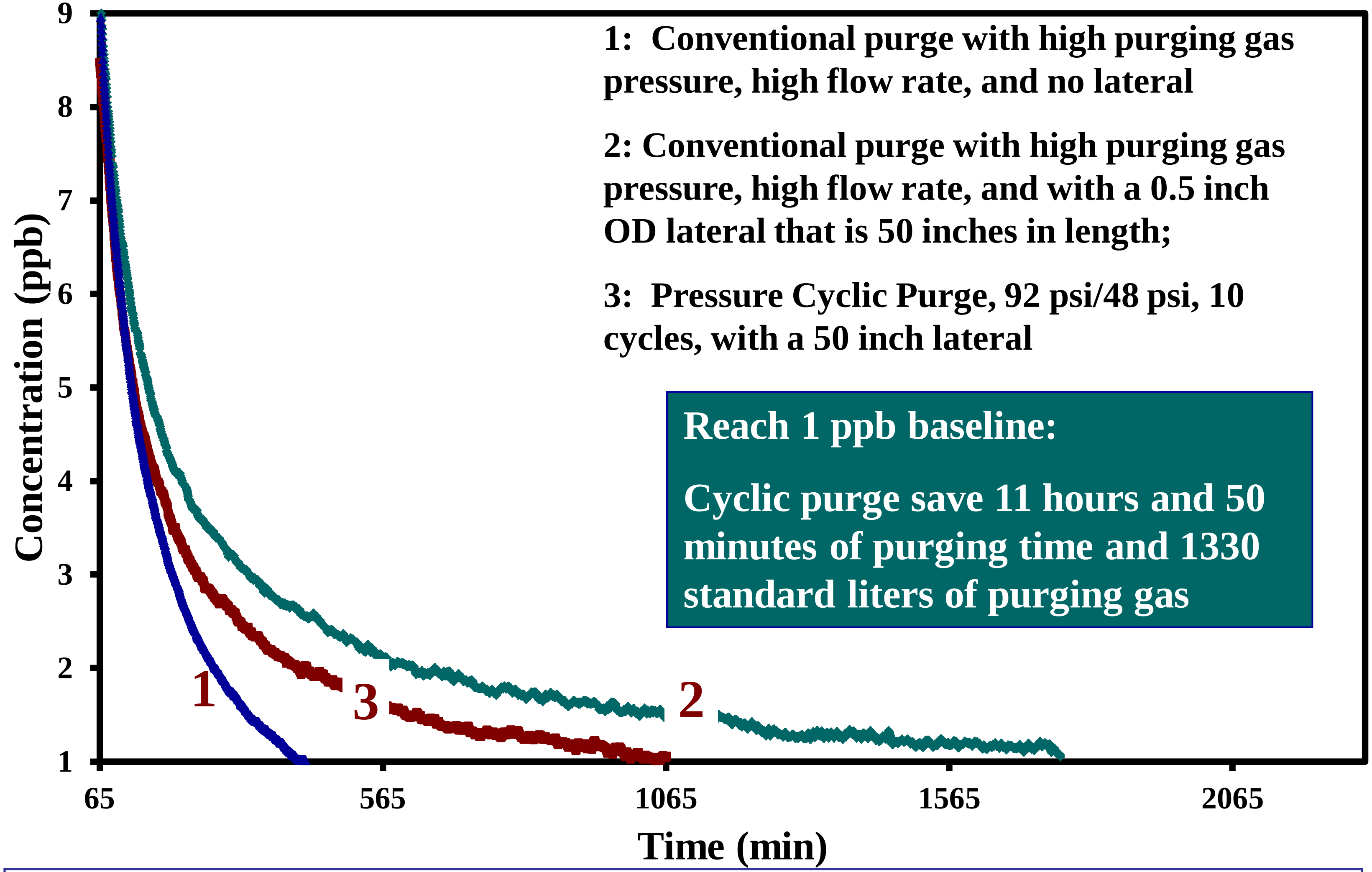
Comparison of Pressure Cyclic Purge with Conventional Purge (w/ Lateral)

Main header: 1.5” OD, 76” length. Lateral: 0.5” OD, 50” length. Initial conc. 380 ppb



1: Conventional purge with high purging gas pressure, high flow rate, and no lateral

2: Conventional purge with high purging gas pressure, high flow rate, and with a 0.5 inch OD lateral that is 50 inches in length;

3: Pressure Cyclic Purge, 92 psi/48 psi, 10 cycles, with a 50 inch lateral

Reach 1 ppb baseline:

Cyclic purge save 11 hours and 50 minutes of purging time and 1330 standard liters of purging gas

Experimental Comparison of PCP with Conventional Purge Highlights

PCP technique achieved baseline quicker and with less purge gas than conventional purge

The addition of a lateral resulted in drastic increases in purge time and gas usage to achieve baseline

PCP appears to have a greater affect in a system with a lateral

Purge Process Simulator

System Pressure:

$$\frac{\partial P}{\partial t} = -P\frac{\partial u}{\partial x} - u\frac{\partial P}{\partial x}$$

Velocity:

$$\frac{\partial u}{\partial t} = -\frac{RT}{PM}\frac{\partial P}{\partial x} - u\frac{\partial u}{\partial x}$$

Absorbed Moisture:

$$\frac{\partial C_s}{\partial t} = k_a C_g (S_0 - C_S) - k_d C_s$$

Gas Phase Moisture:

$$\frac{\partial C_g}{\partial t} = D_L \frac{\partial^2 C_g}{\partial x^2} + \frac{\partial D_L}{\partial x}\frac{\partial C_g}{\partial x} - u\frac{\partial C_g}{\partial x} - C_g\frac{\partial u}{\partial x} + \frac{4}{d}\left[(k_d C_S - k_a C_g (S_0 - C_S))\right]$$

C_S: moisture concentration on pipe wall, mol/cm^2; C_g: moisture concentration in gas, mol/cm^3;

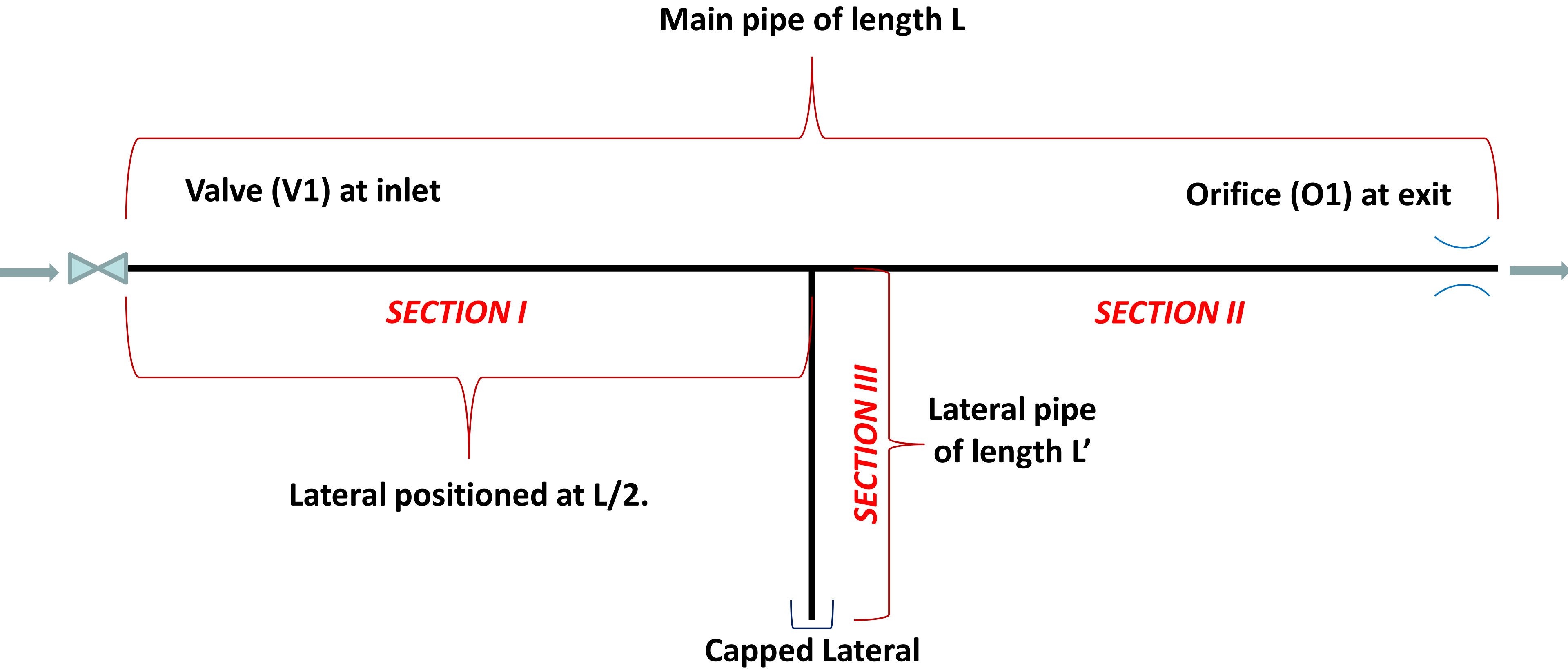
k_{ads}: adsorption rate constant, cm^3/mol/s; k_{des}: desorption rate constant, 1/s

S_0: site density of surface adsorption, mol/cm^2; D_L: dispersion coefficient, cm^2/s;

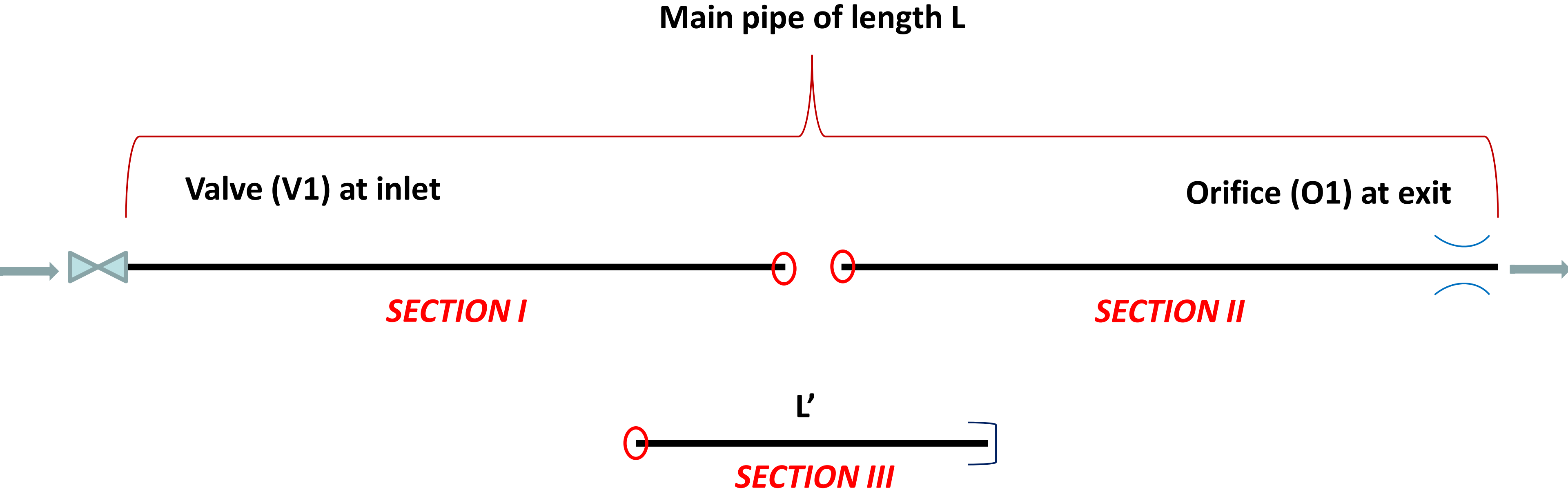
u: velocity, cm/s; d: diameter; P: pressure

The simulator is scalable and applicable to various system configurations and sizes

Purge Process Simulator



Purge Process Simulator

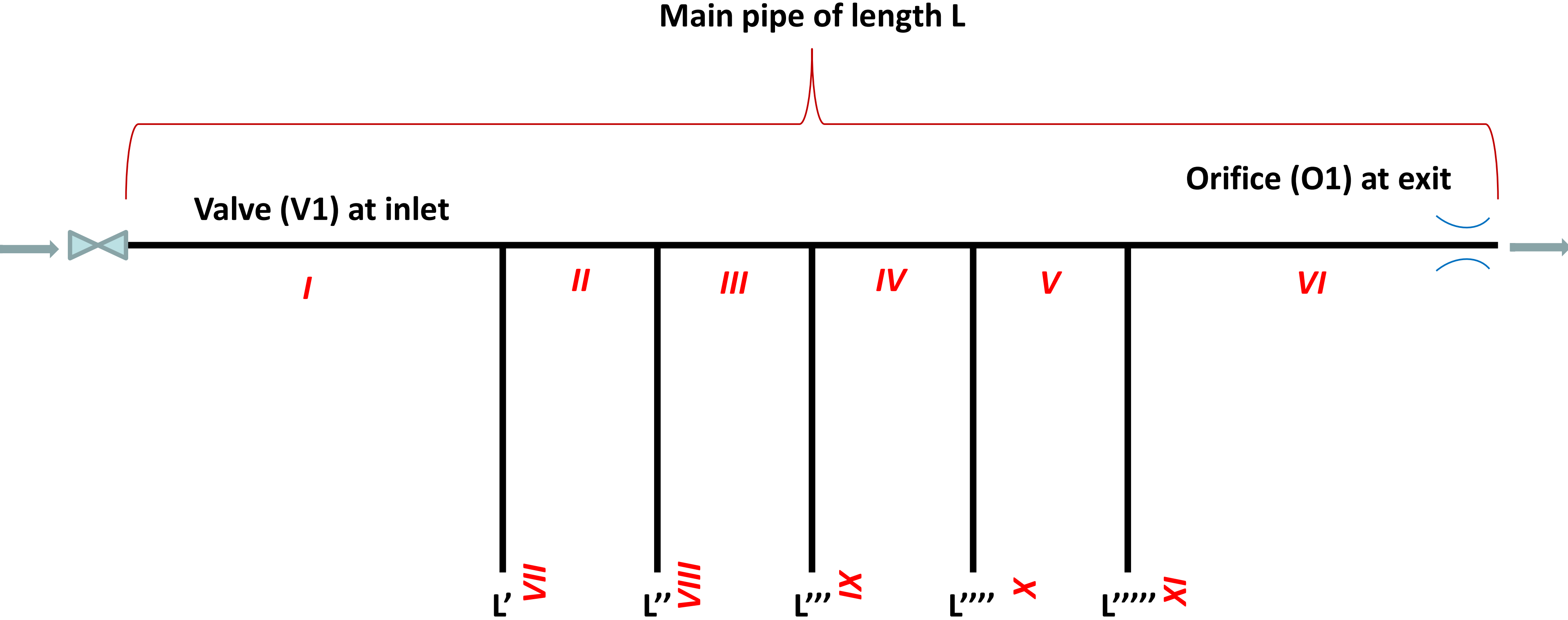


abrupt changes (discontinuities) in gas velocity and the flux of moisture at the intersection point (highlighted with red circles)

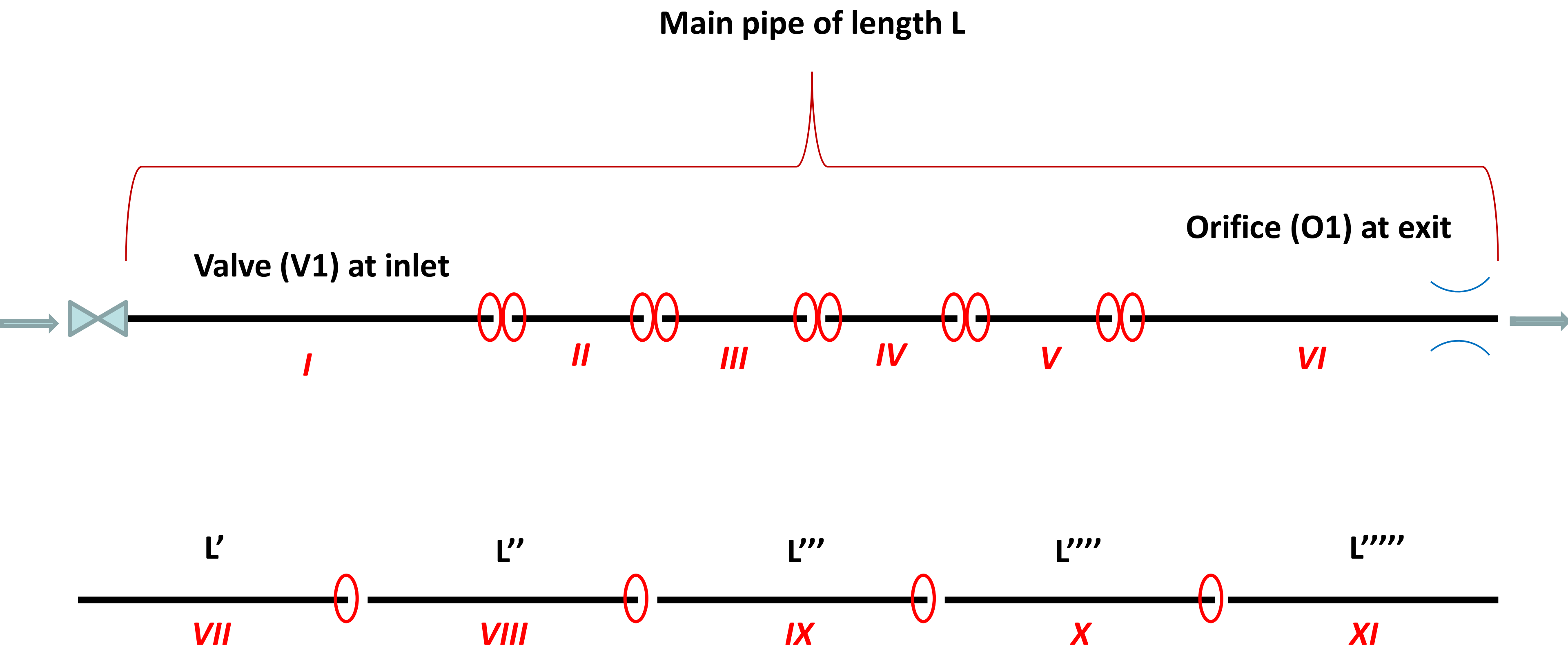
continuity in pressure, moisture concentration

modular approach for ease of simulation

Purge Process Simulator



Purge Process Simulator



This technique can be applied to a wide variety of geometries

Purge Process Simulator Highlights

Dividing system into sections takes a multi-dimensional geometry and transforms it into a one dimensional geometry

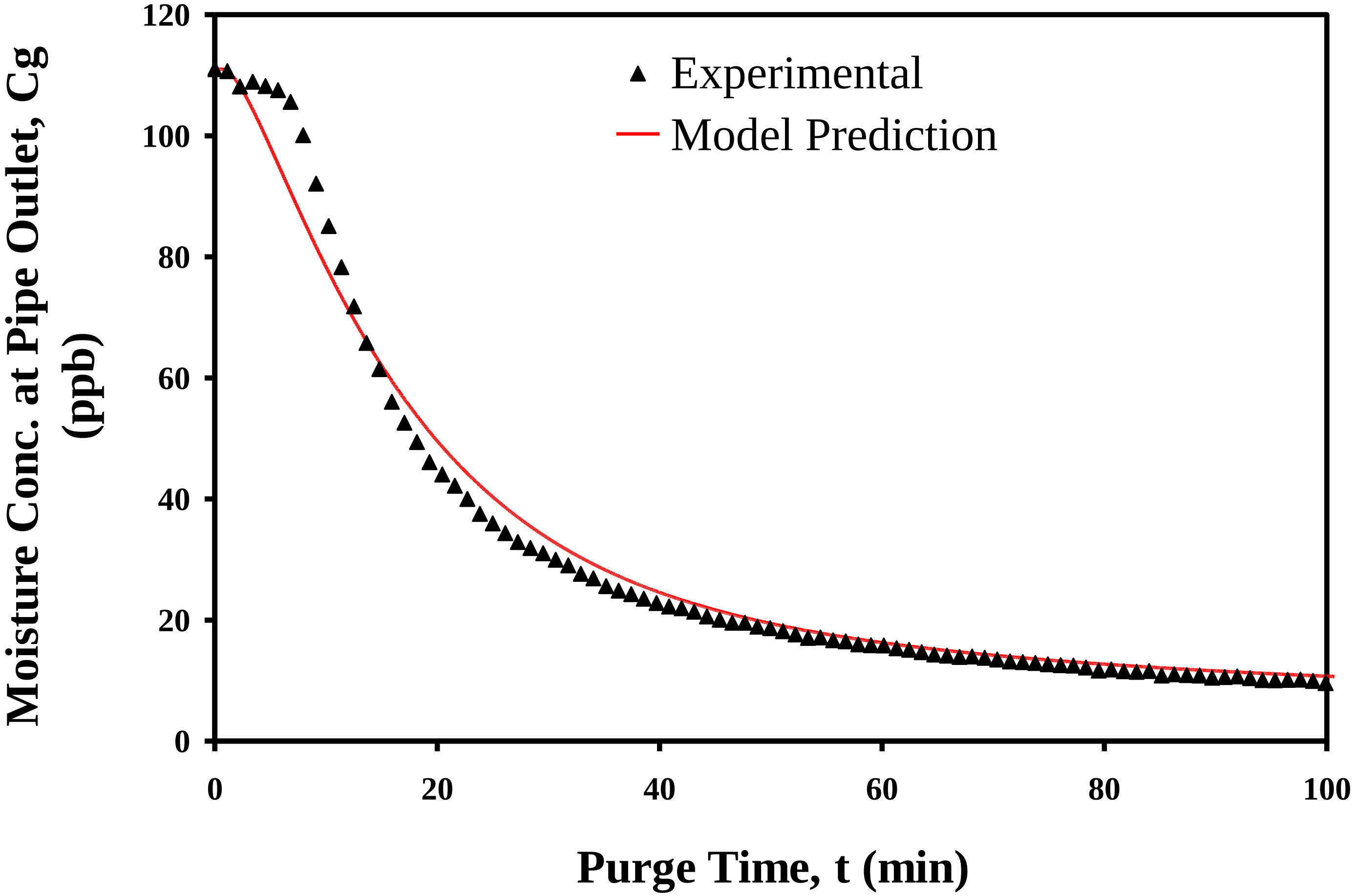
Each section has four PDEs and there associated initial and boundary conditions

This modeling scheme allows for continuity in some dependent variables whilst allowing discontinuity is other dependent variables

The simulator is scalable and applicable to various system configurations and sizes.

Simulator Verification- Predicting Conventional Purge

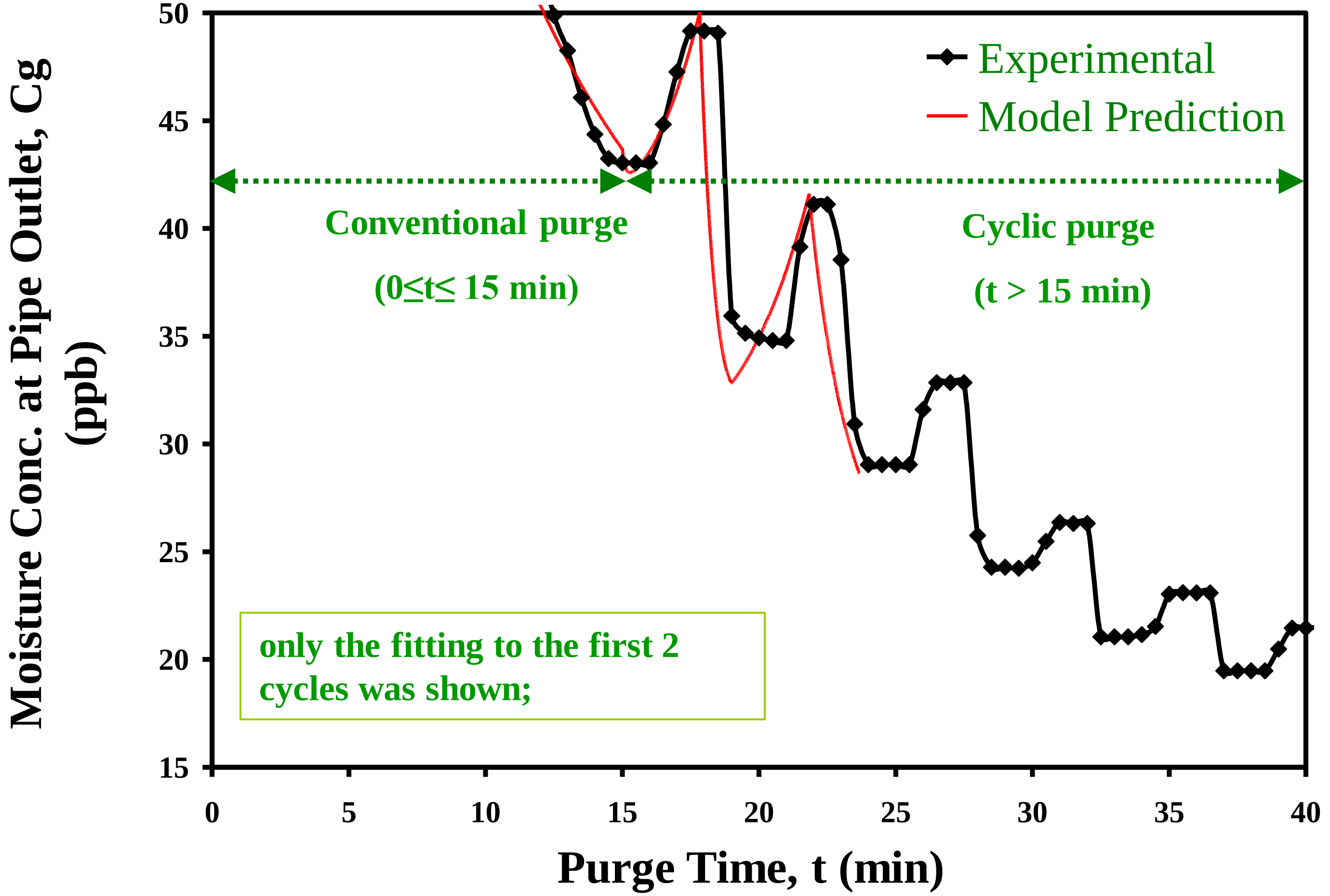
EP SS pipe with 1.5 inch OD and 76 inch length. Initial conc. 115 ppb



The process simulator well predicts conventional purge process

Simulator Verification- Predicting Pressure-cyclic Purge

EP SS pipe with 1.5 inch OD and 76 inch length. Initial conc. 350 ppb

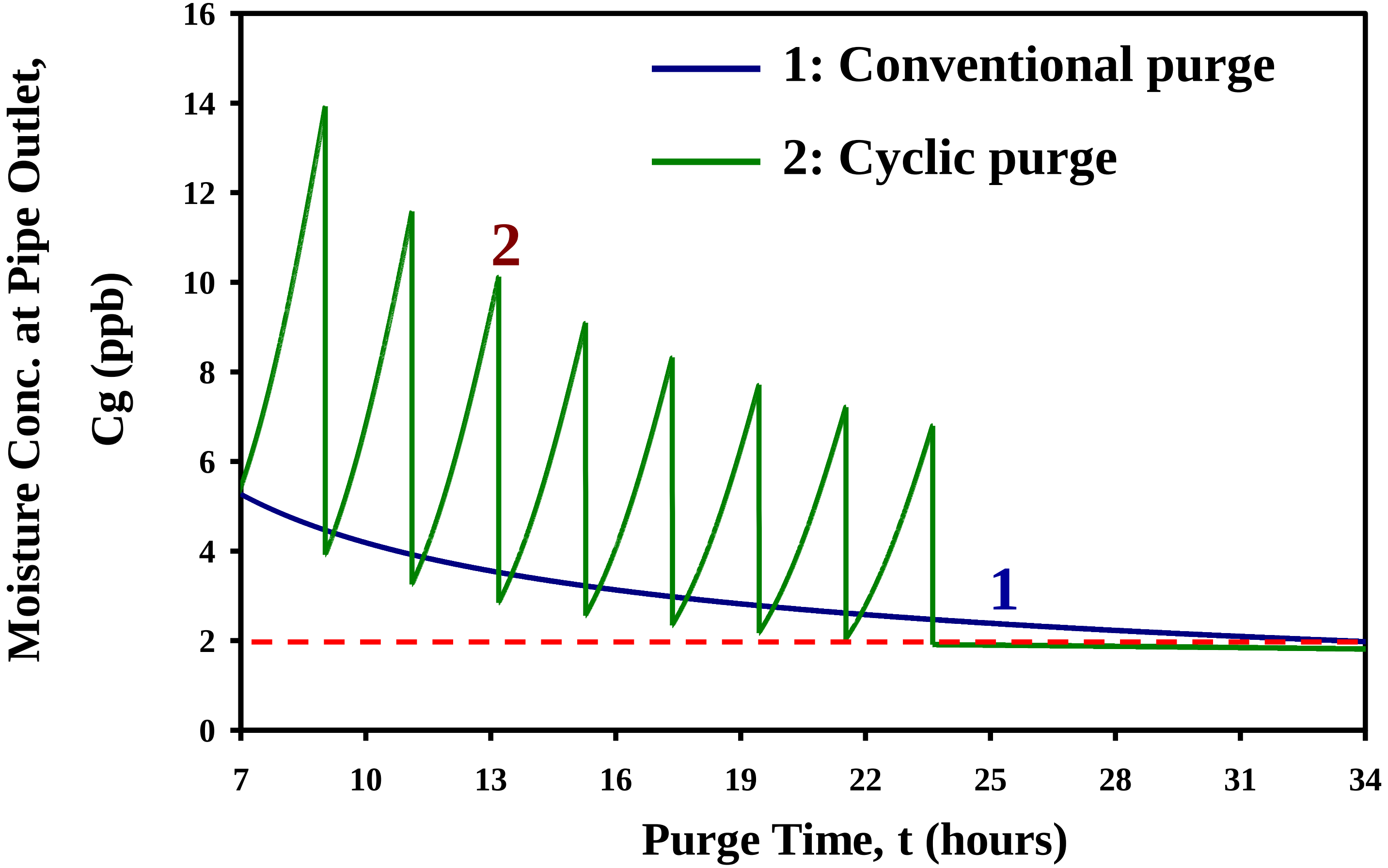


only the fitting to the first 2 cycles was shown;

The process simulator well predicts combination of conventional and cyclic purge processes

PSP vs. Conventional Purge w/o Lateral

EP SS pipe with 1.5 inch OD and 1640 feet length; no laterals. Initial conc. 200 ppb; cyclic purge starts when the moisture concentration reaches 5 ppb.



To reach 2 ppb baseline: ***conventional purge: 34 hours; Cyclic purge: 23 hours; cyclic purge saves 76% of purge gas***

A Comparison of PCP with Conventional Purge w/o Laterals

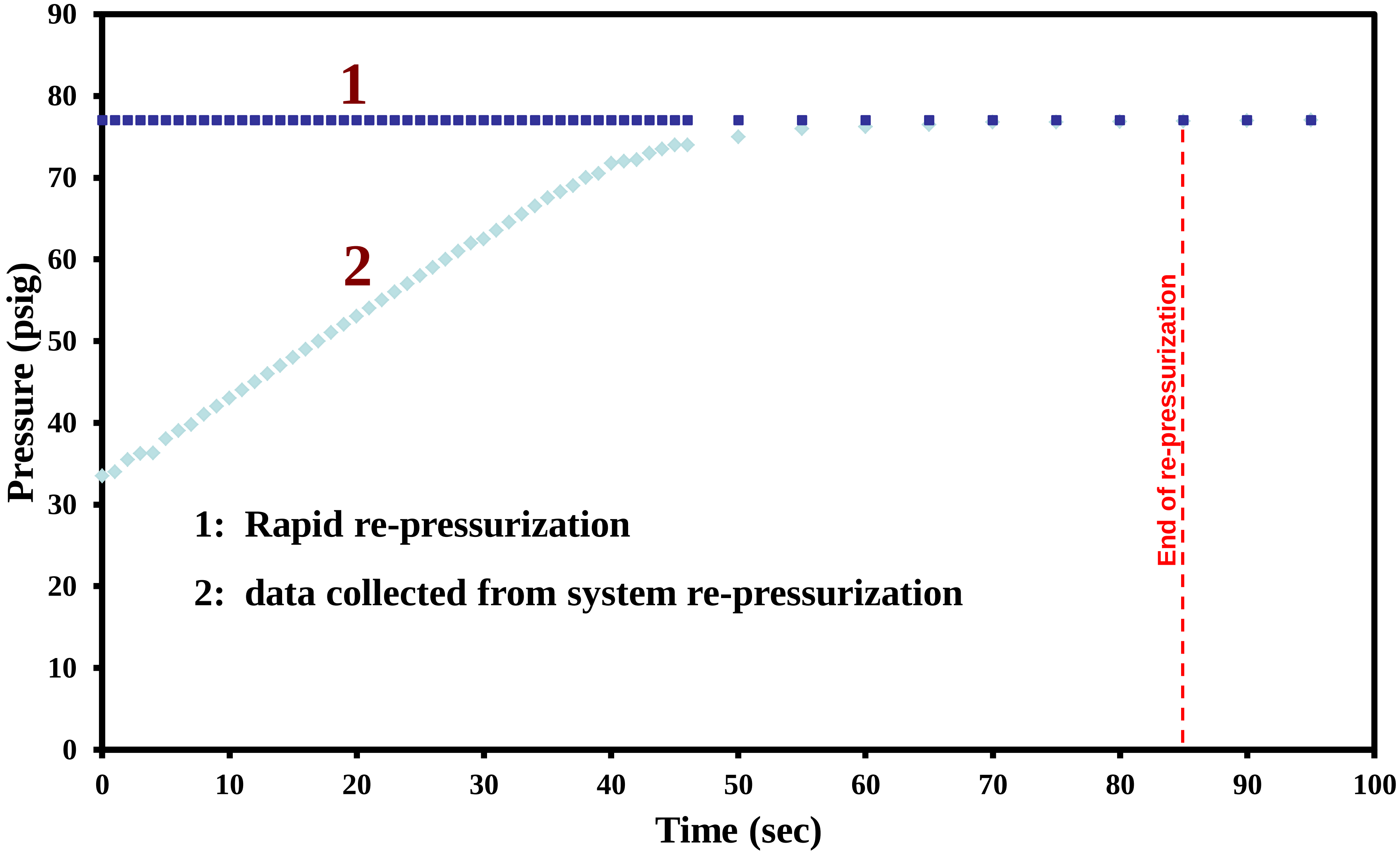
The simulation was successfully verified against experimental results and fitting parameters found

Simulations show that PCP technique was faster at achieving baseline while using less purge gas

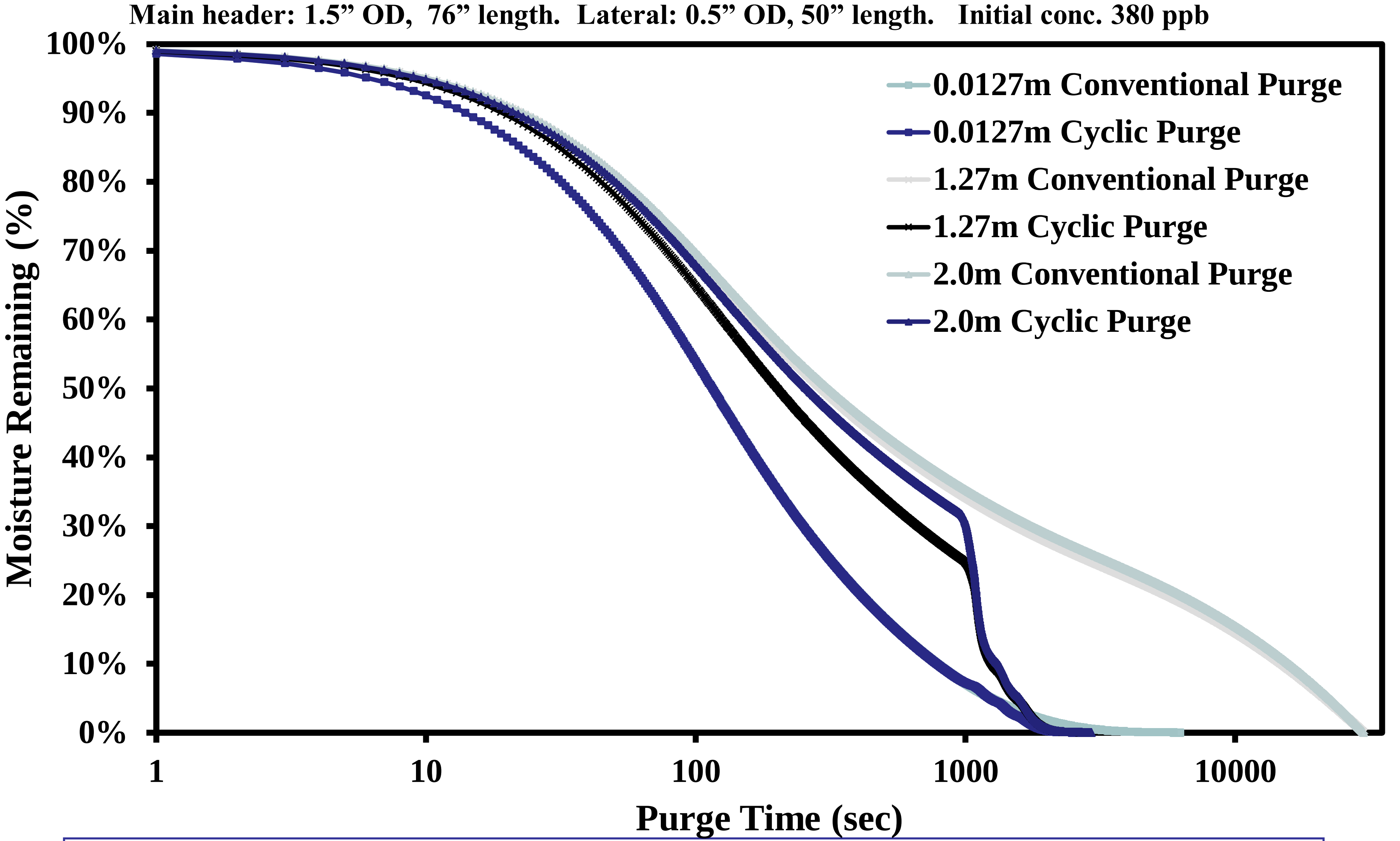
The model was successfully scaled up and showed a that PCP achieved even more savings in purge time and purge gas

Purge Process Simulator Improvement

EP SS main header with 1.5 inch OD and 76 inch length. One 0.5 inch OD lateral with a 50 inch length. Initial conc. 380 ppb



Comparison of Pressure Cyclic Purge with Conventional Purge (w/ Lateral)



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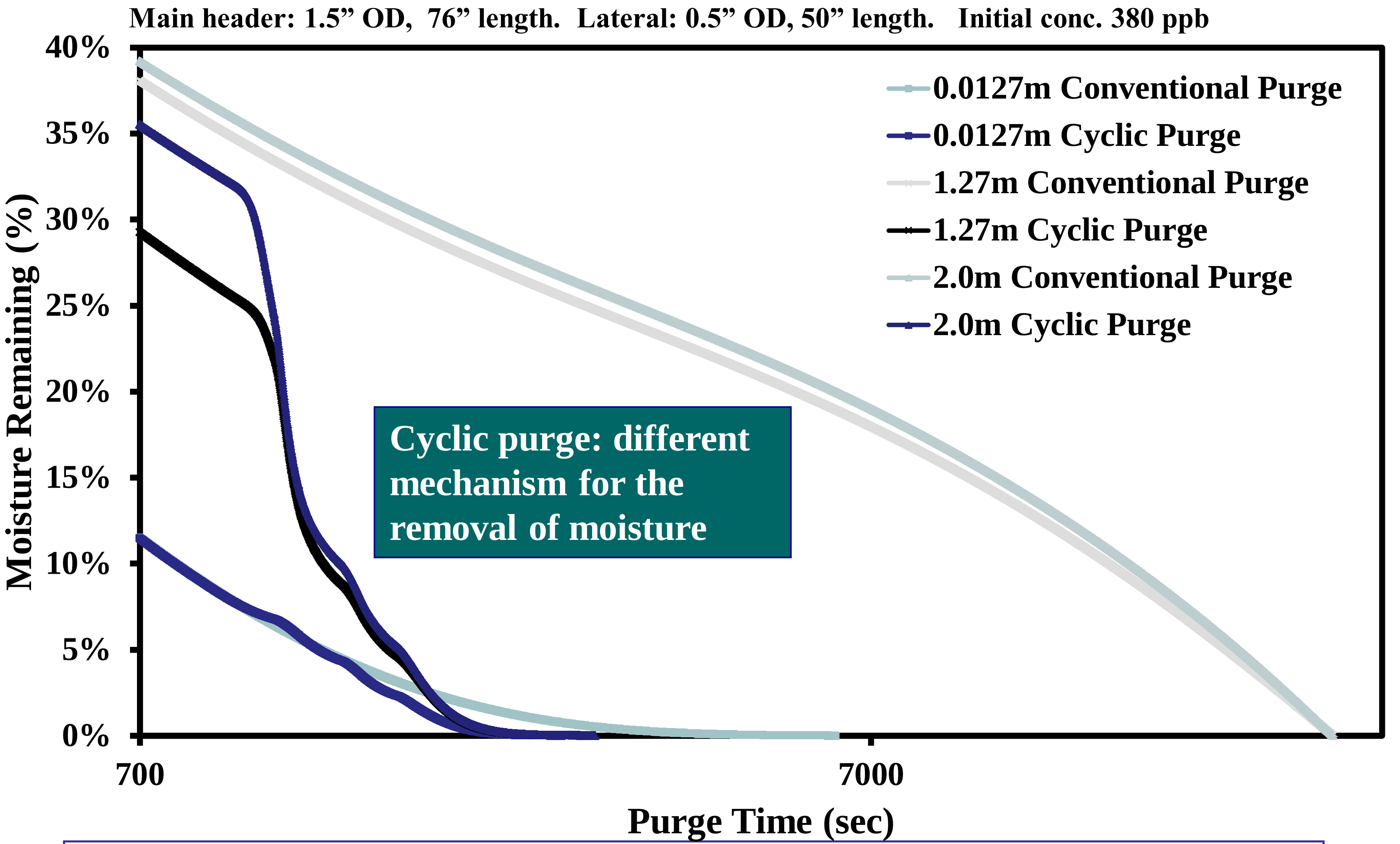
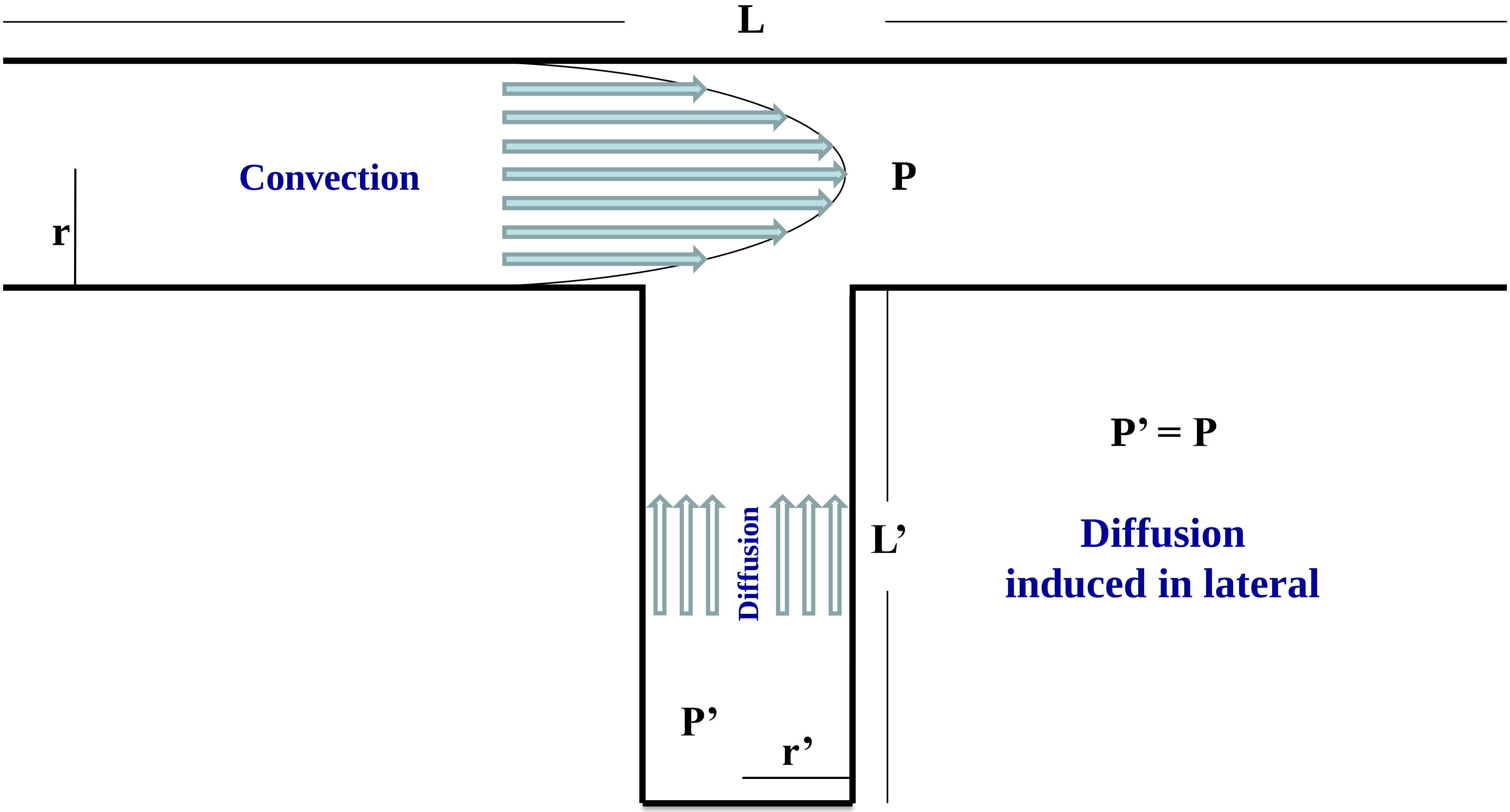


Cyclic purge: different mechanism for the removal of moisture

Conventional Purge Mechanism

Main header: 1.5” OD, 76” length. Lateral: 0.5” OD, 50” length. Initial conc. 380 ppb



P’ = P

Diffusion induced in lateral

Pressure Cyclic Purge Mechanism

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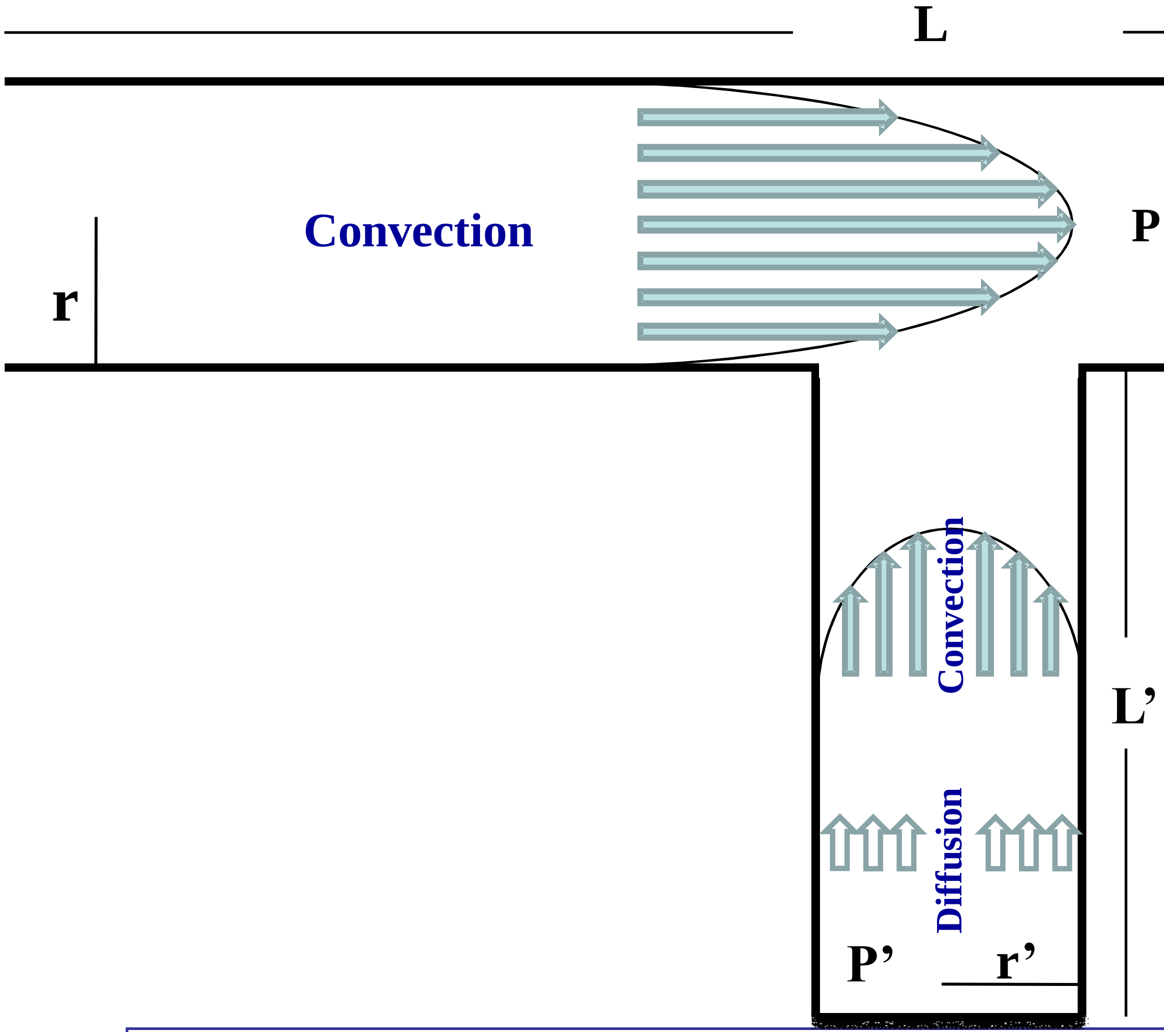
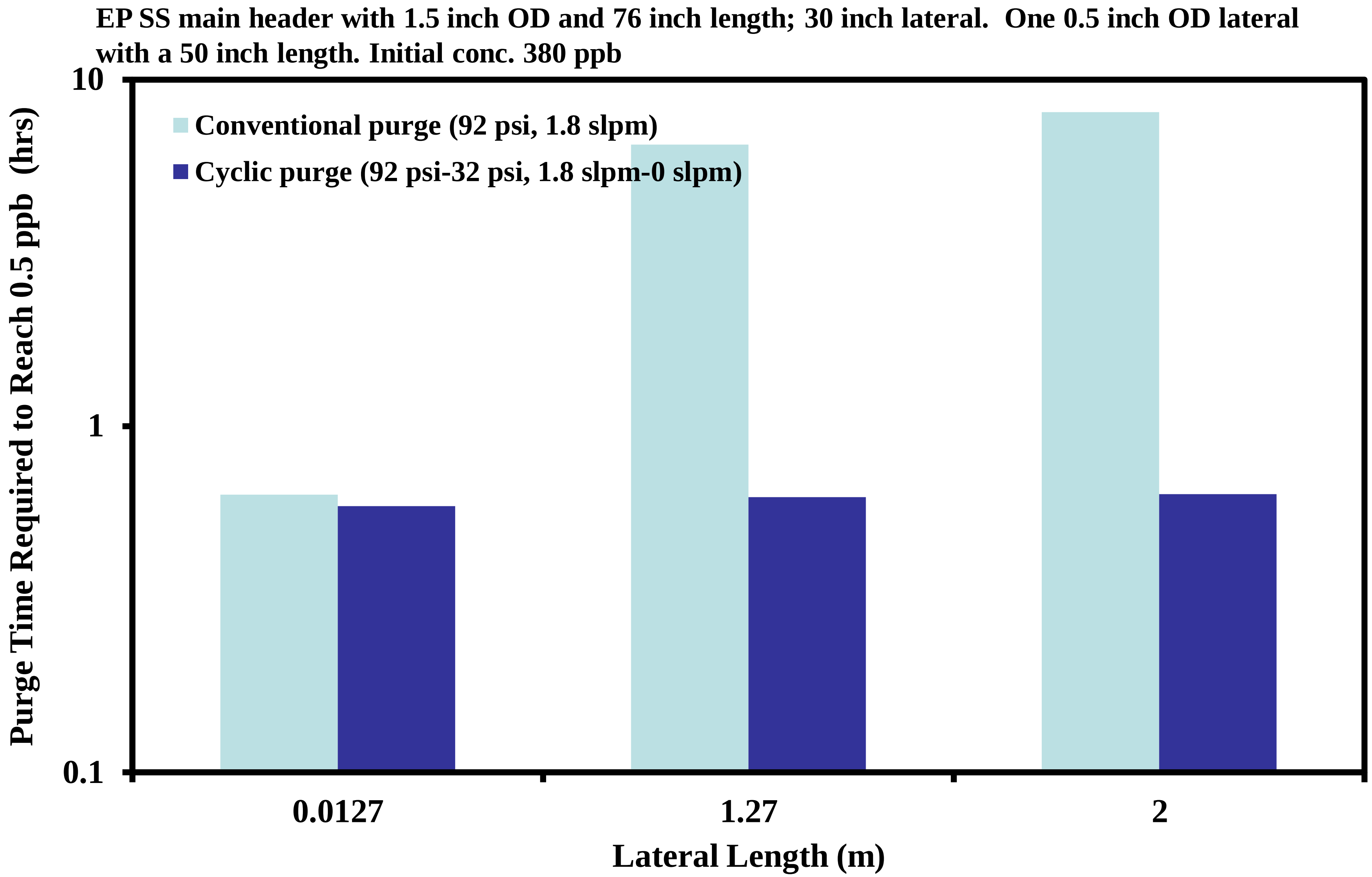


P’ > P

Convection + Diffusion induced in laterals

PCP vs. Normal Purge (w/ Lateral)



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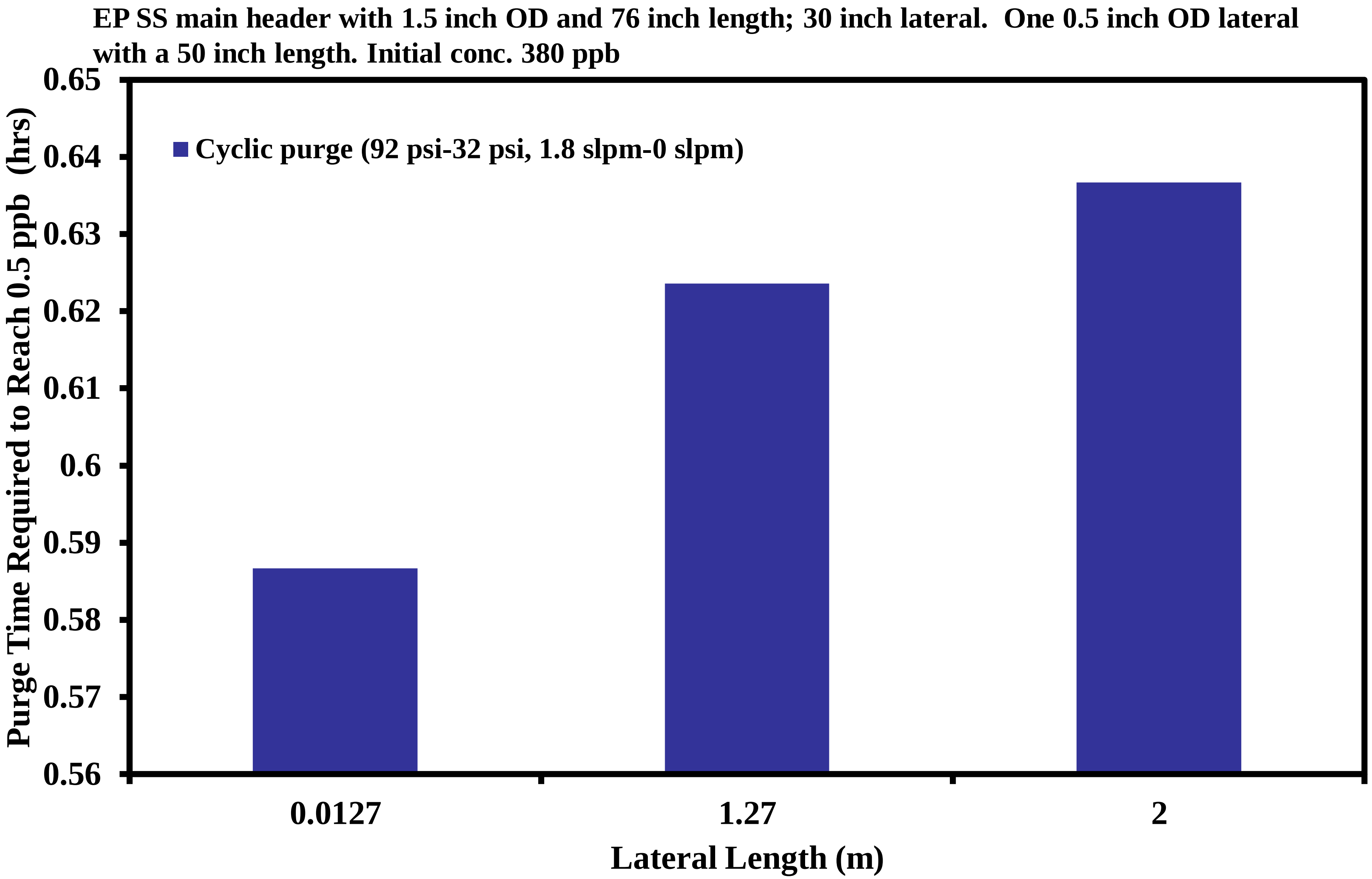
PCP vs. Normal Purge (w/ Lateral)



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PCP vs. Normal Purge (w/ Lateral)

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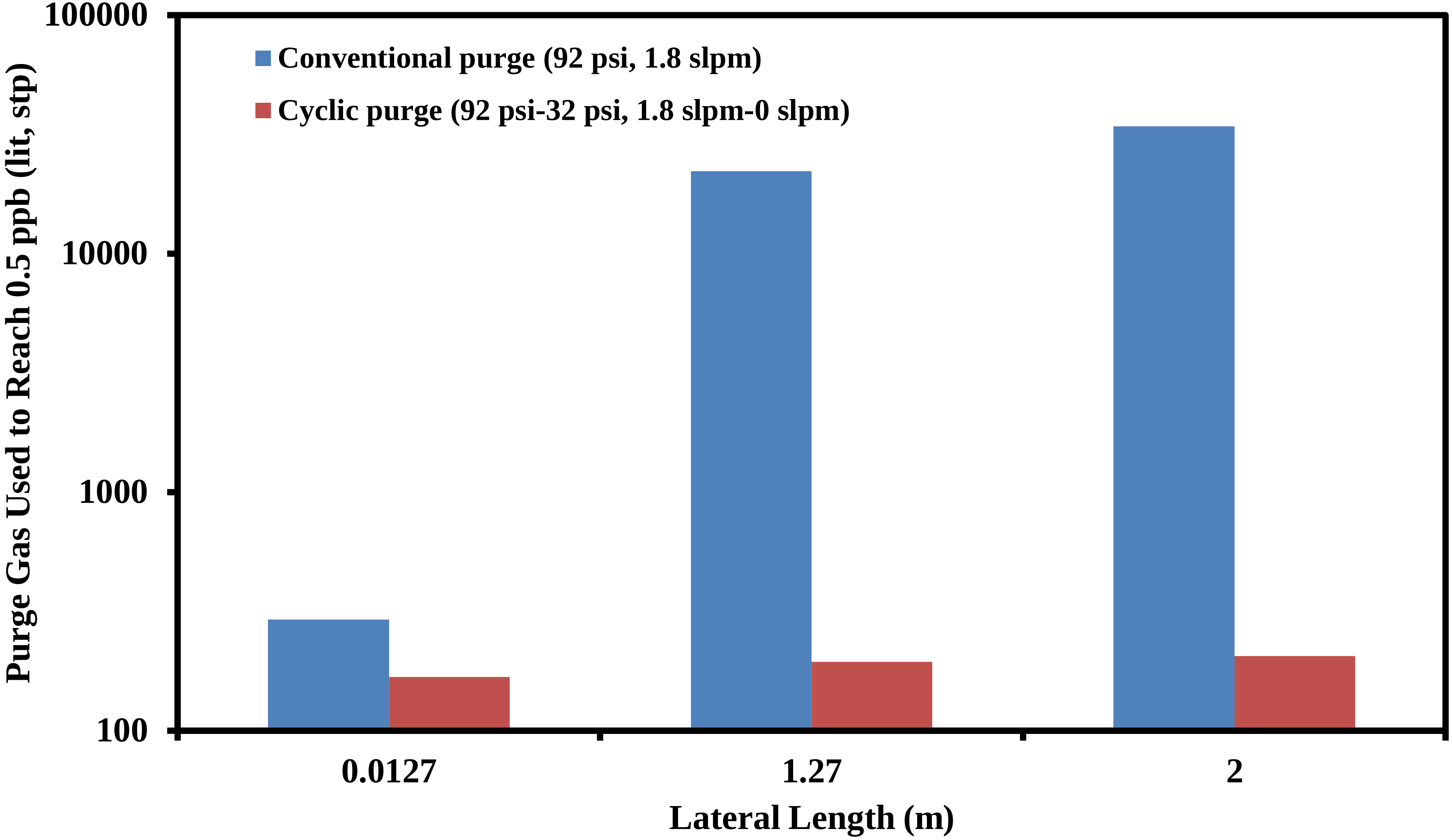

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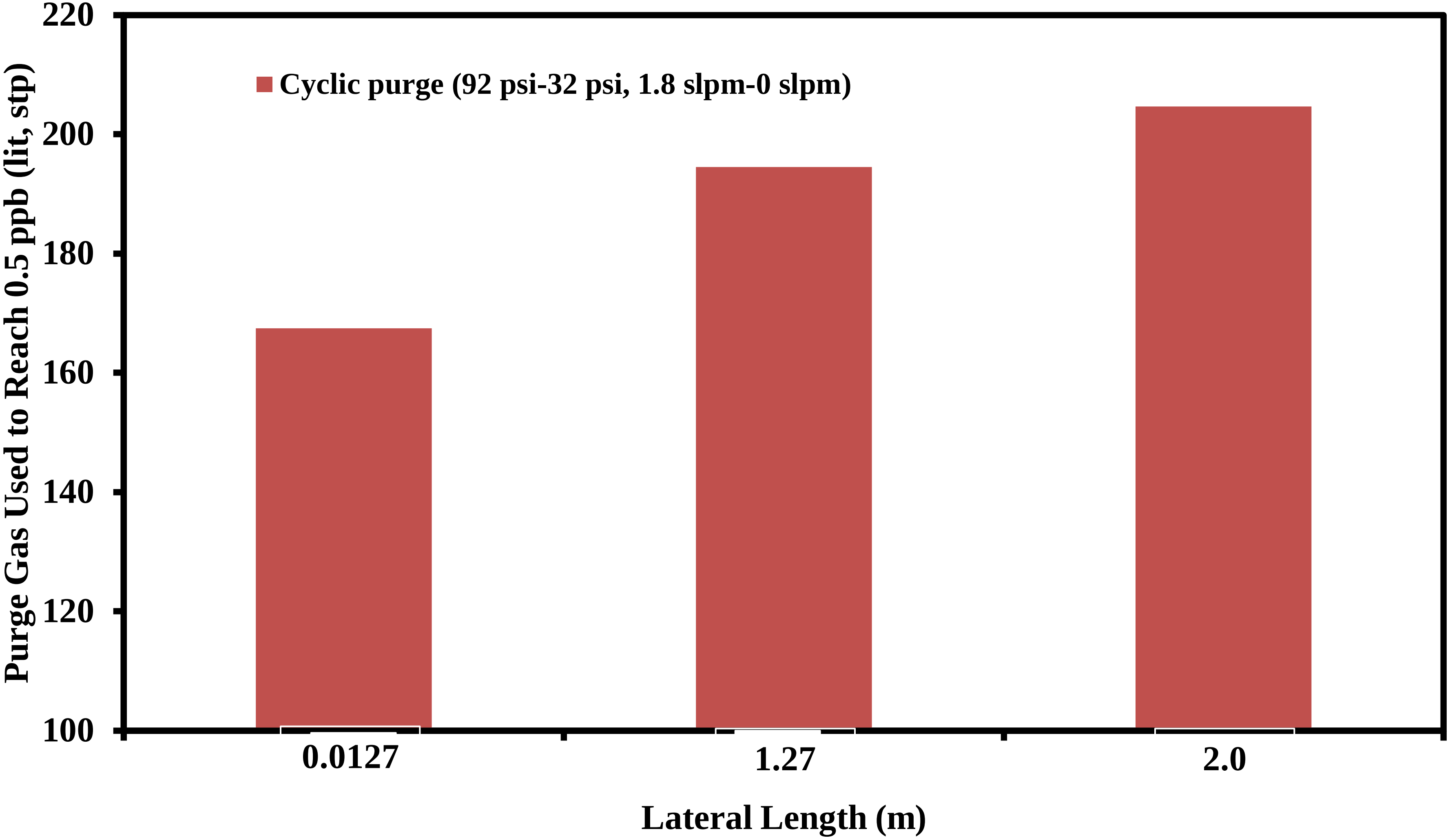

PCP vs. Normal Purge; Lateral Length Comparison

Introducing laterals into a system drastically increases the purge gas and purge time required to achieve baseline

PCP has a much greater effect in systems with laterals versus systems without laterals

PCP appears to become more effective has lateral length, thus dead volume, increases

The mechanism for moisture removal in laterals with a dead volume changes when switching from conventional purge to pressure cyclic purge

PCP vs. Normal Purge (w/ Lateral)

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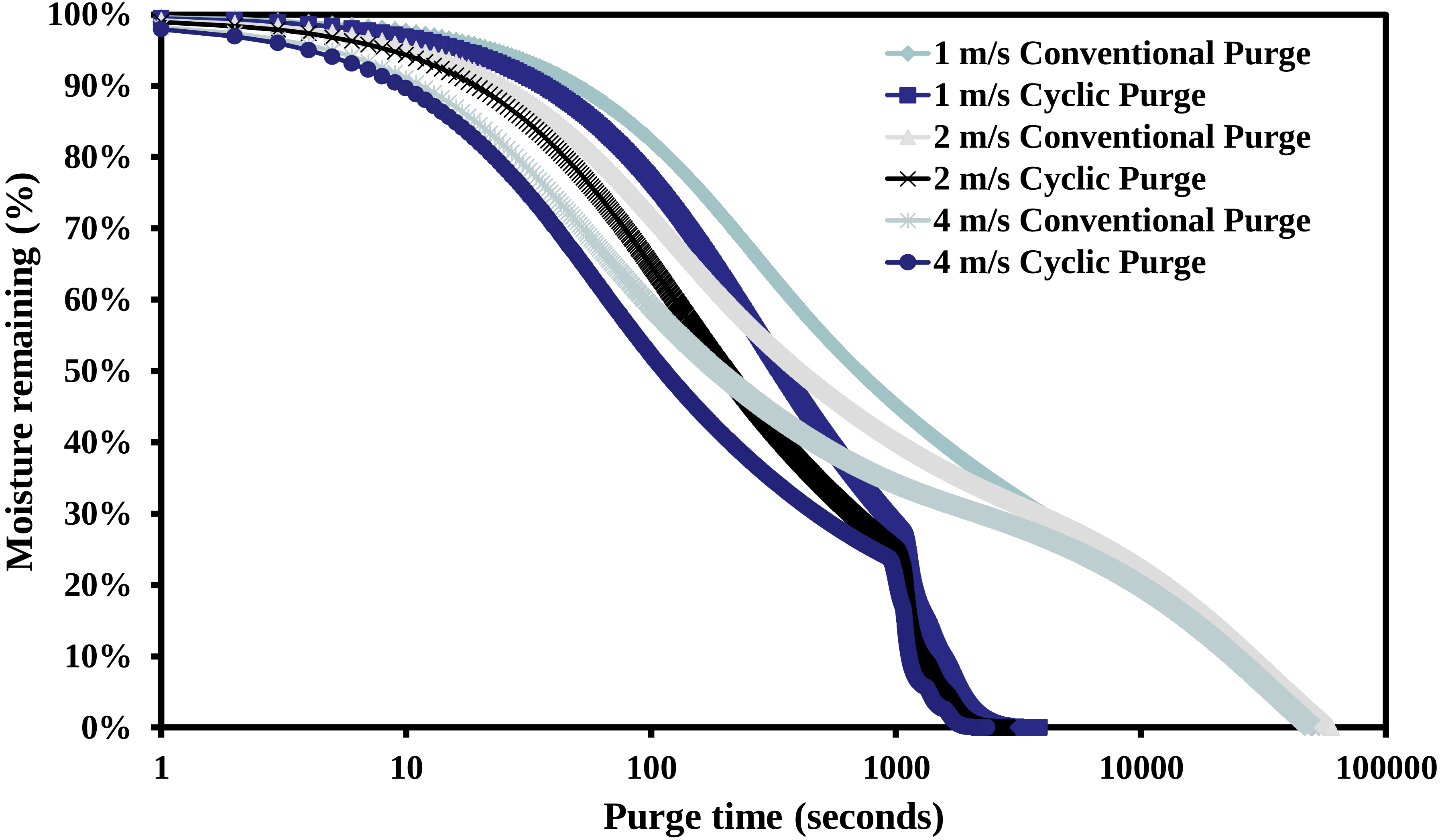

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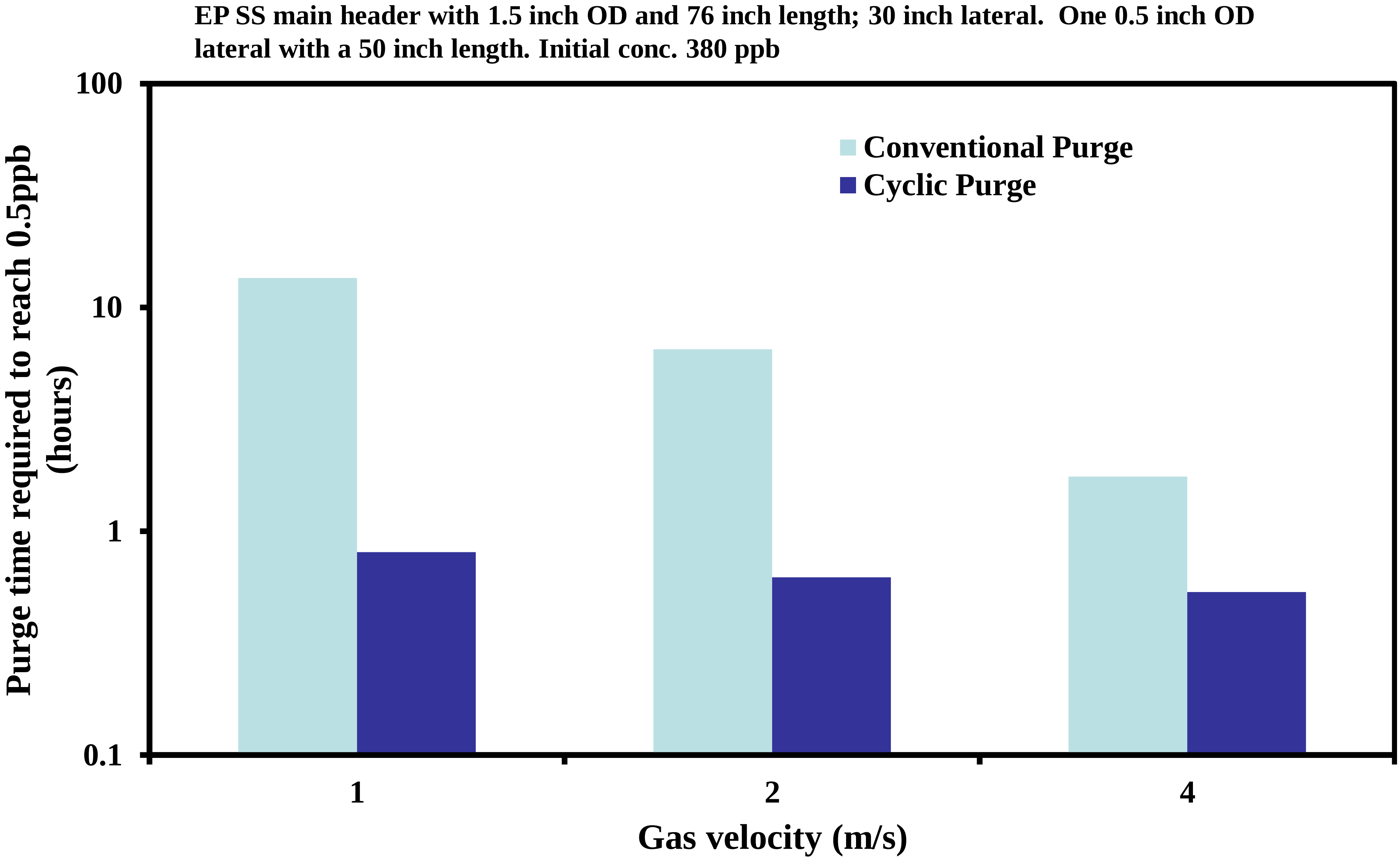

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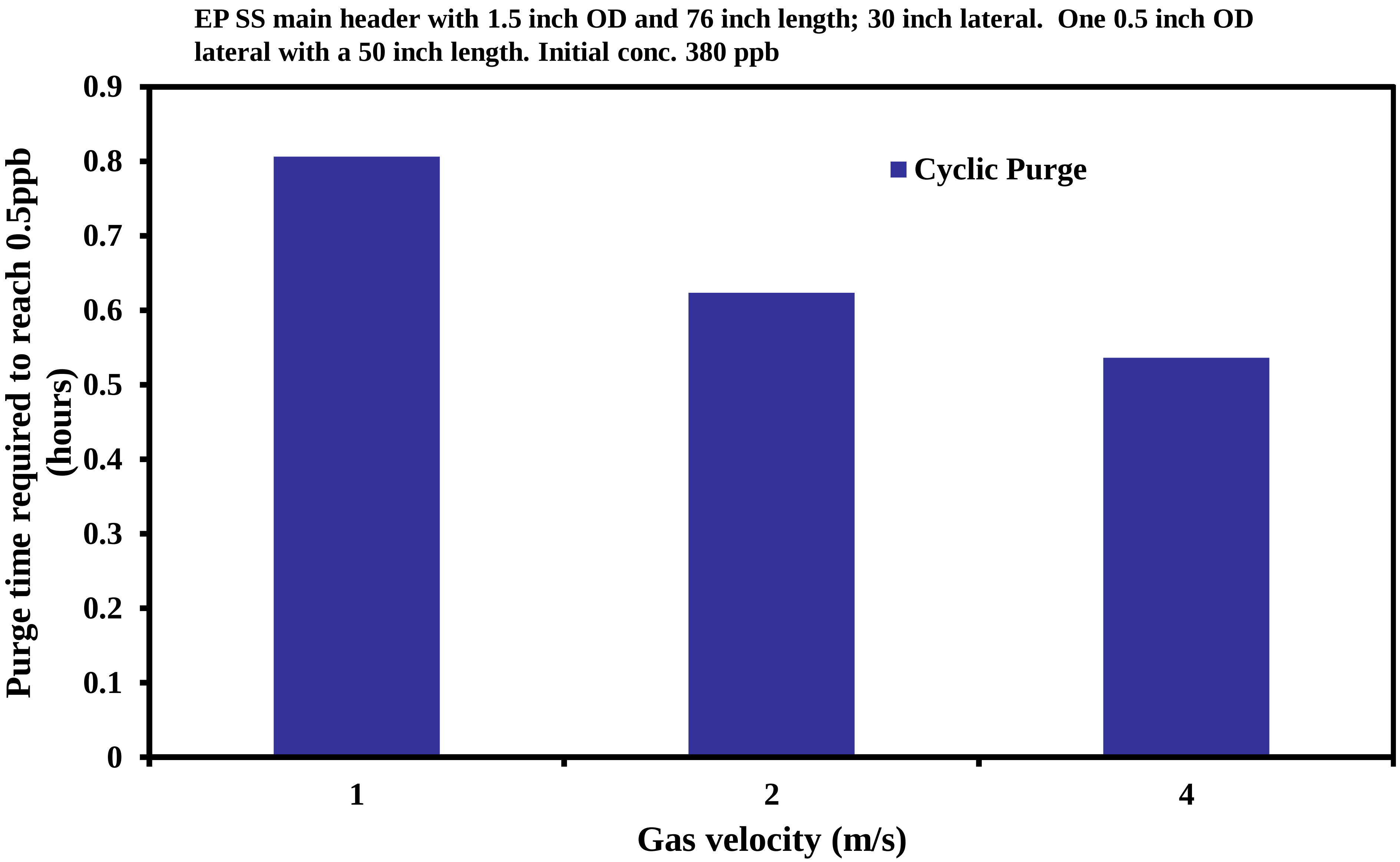

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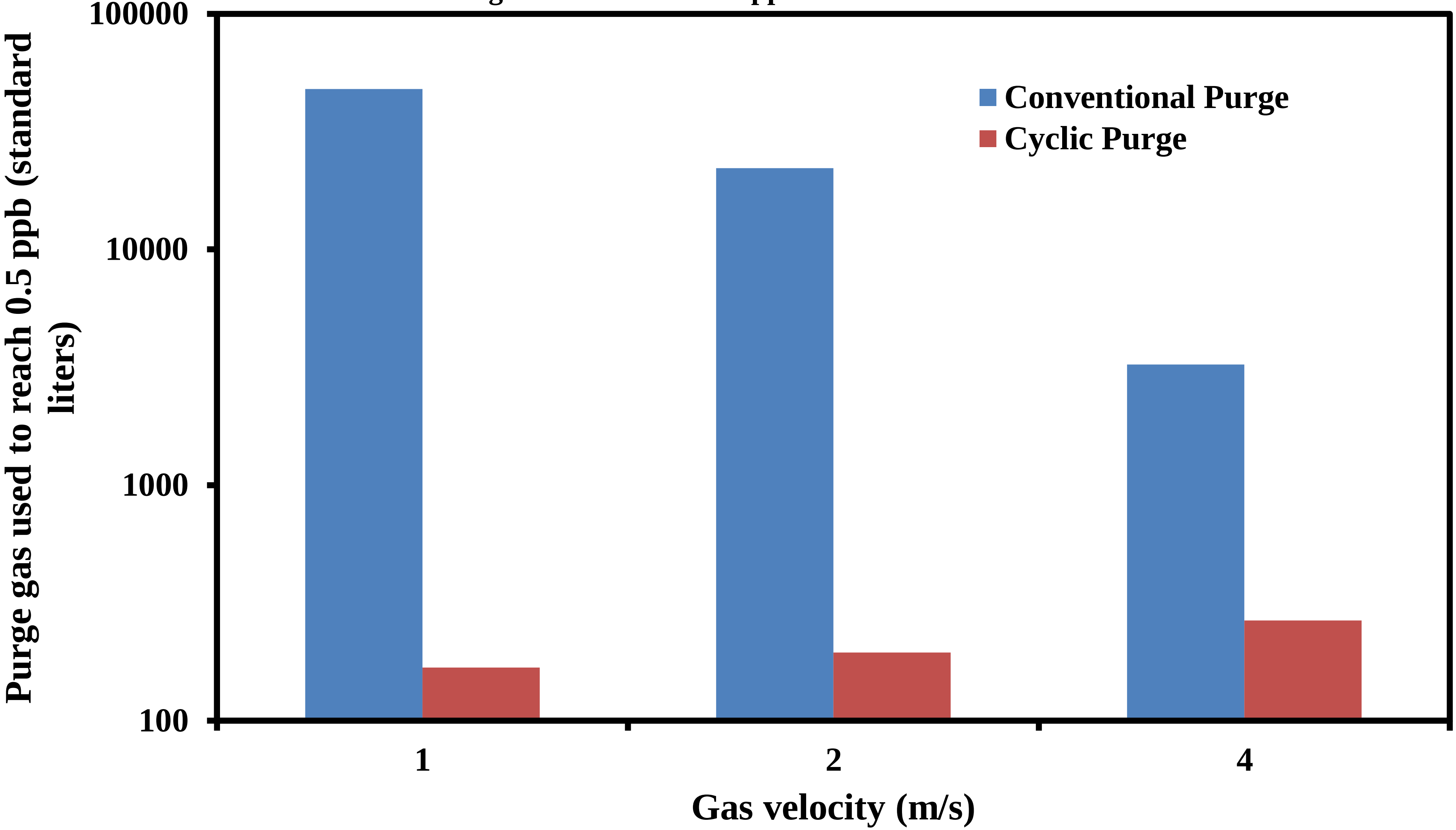

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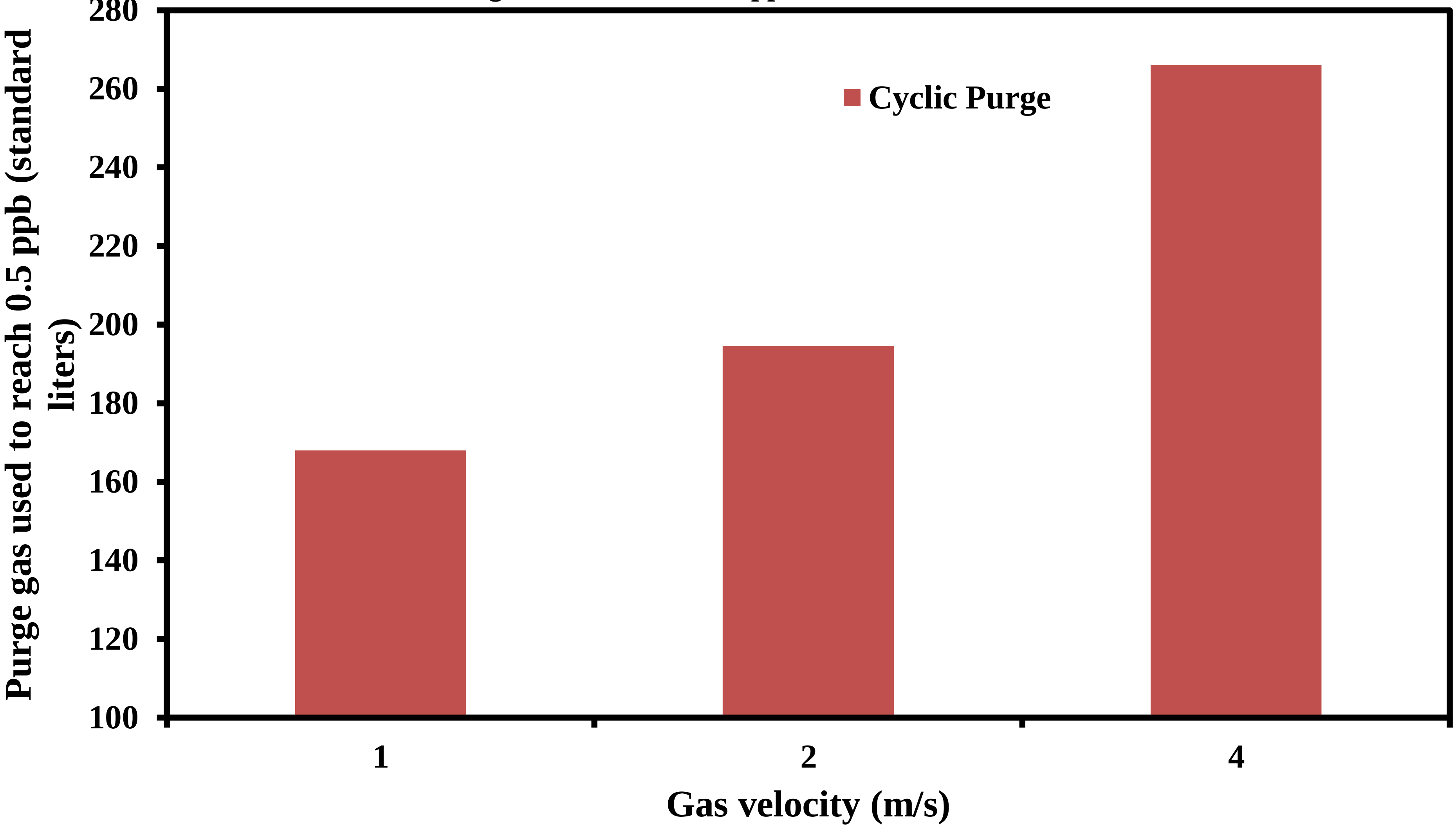

PCP vs. Normal Purge; Gas Velocity Comparison

Increasing gas velocity will decrease purge time required to achieve baseline

For a given baseline, higher gas velocity will require more purge gas

An optimization must be performed to achieved desired result

PCP vs. Normal Purge (w/ Lateral)

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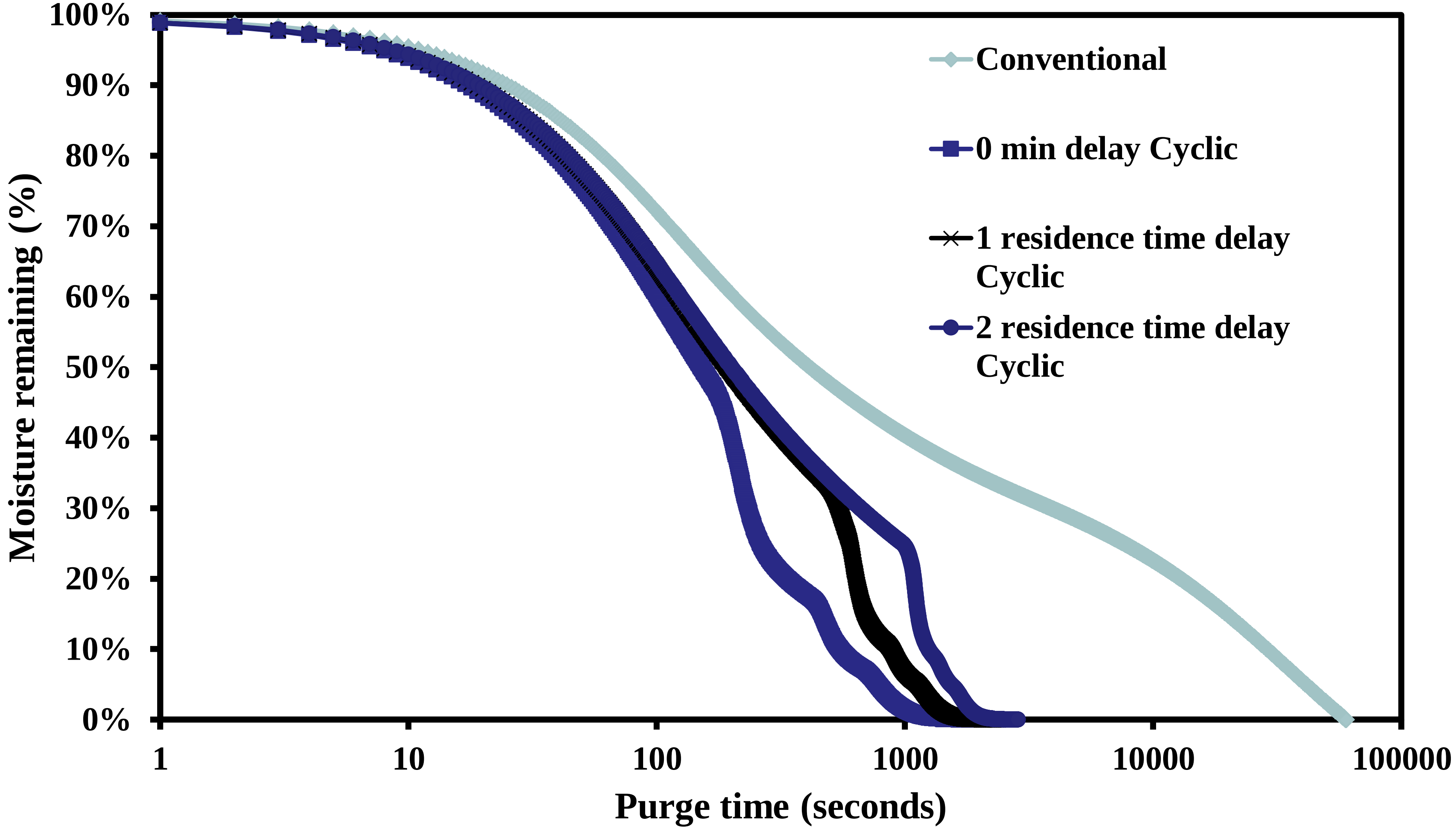

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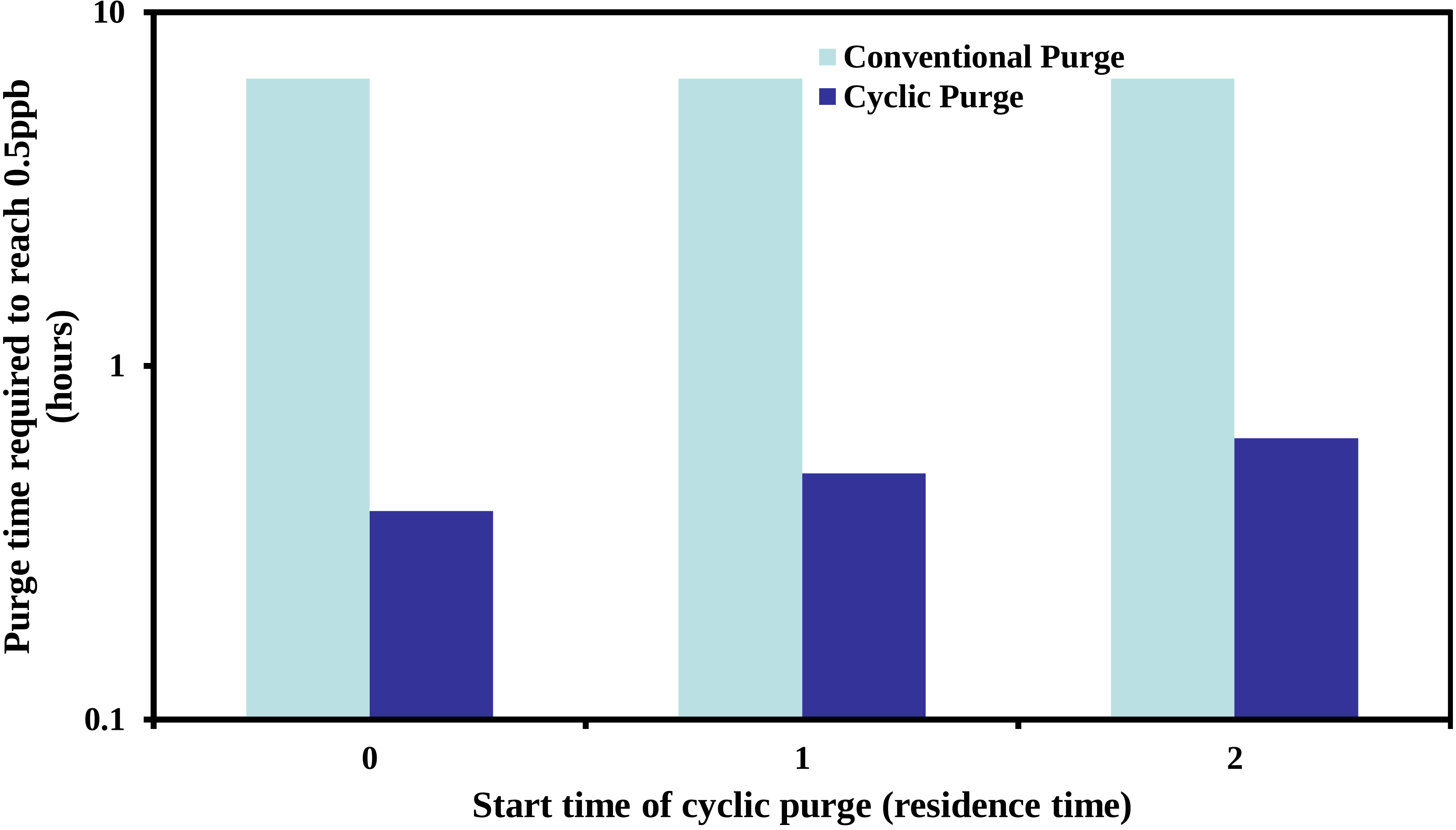

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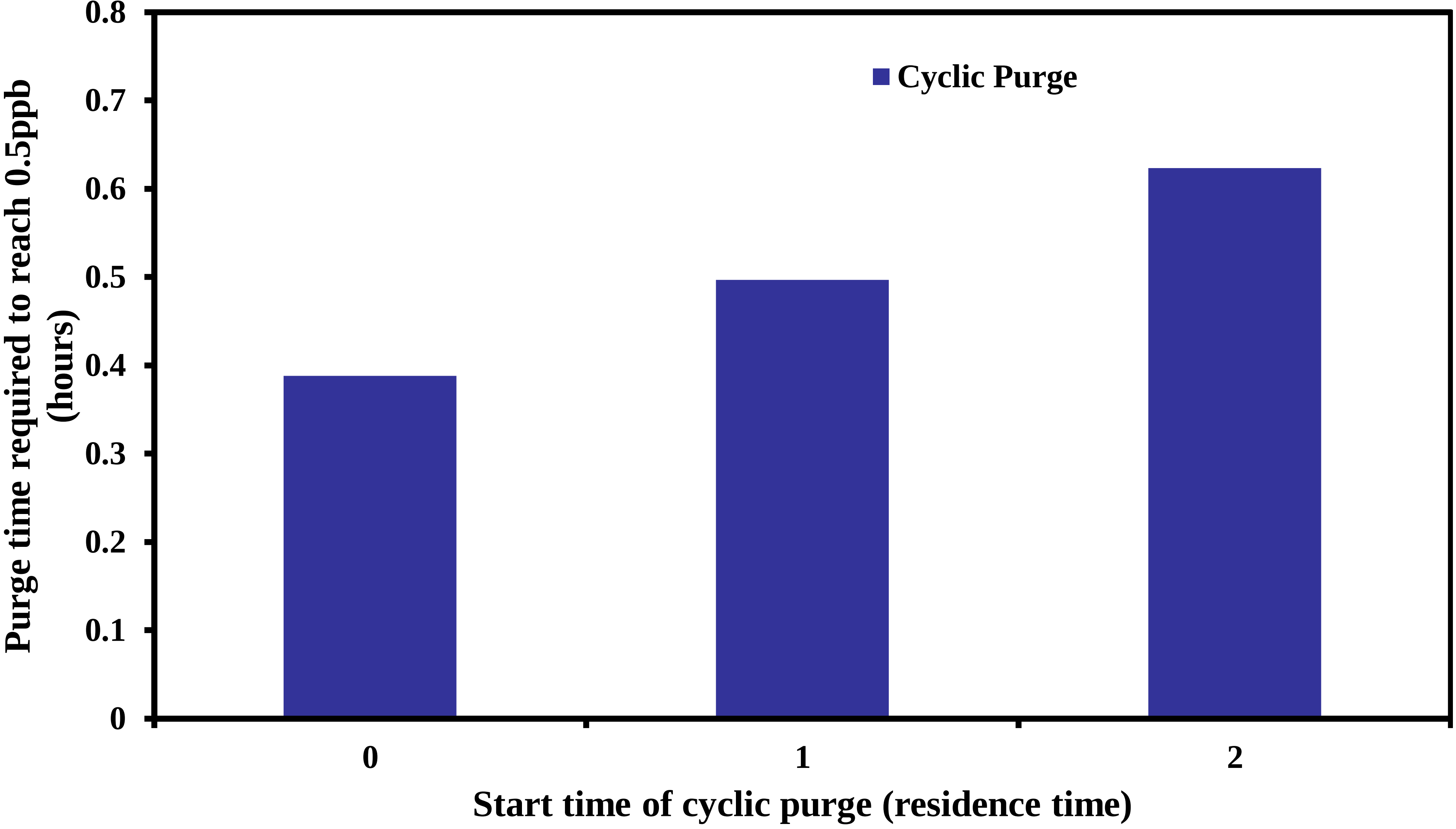

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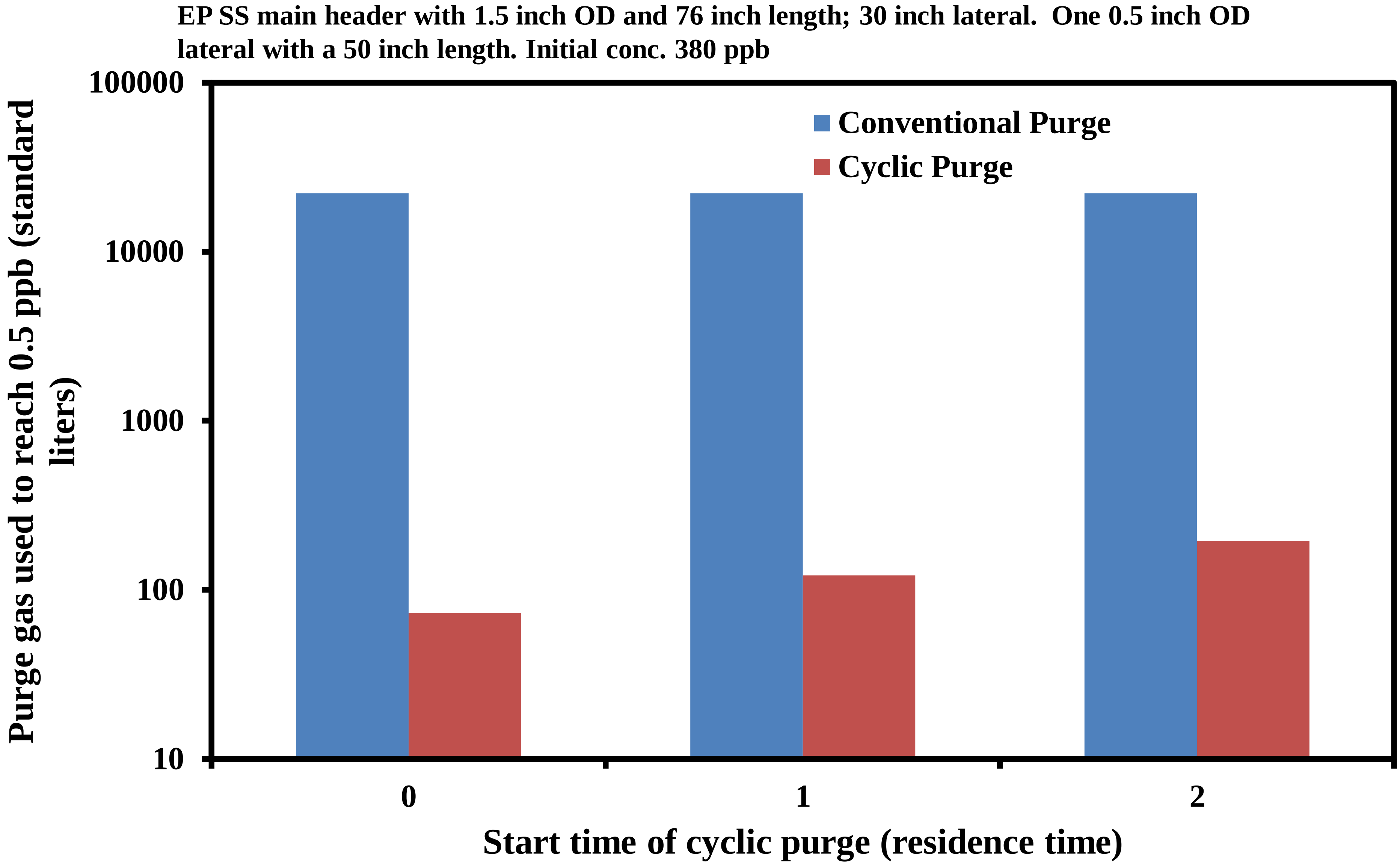

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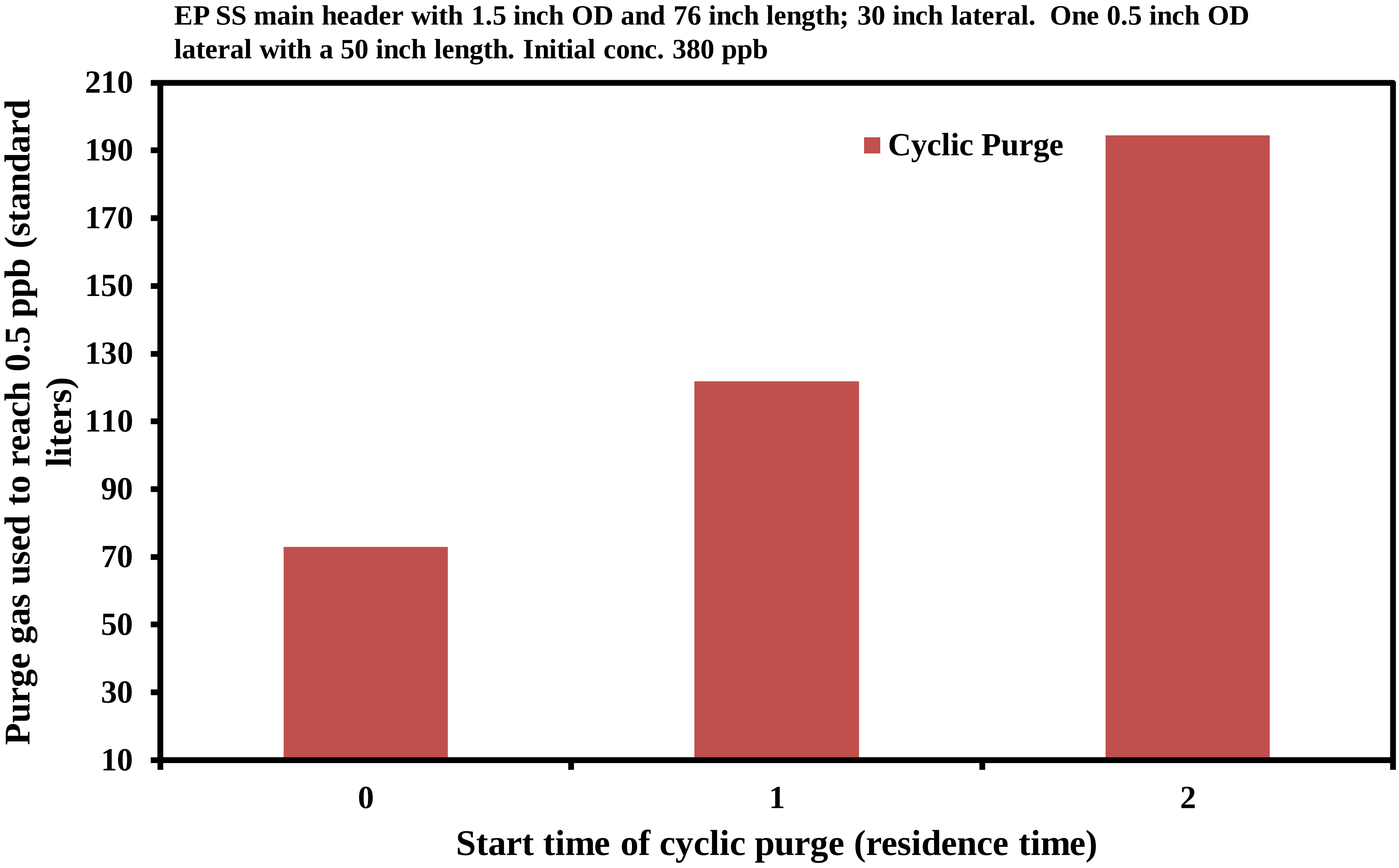

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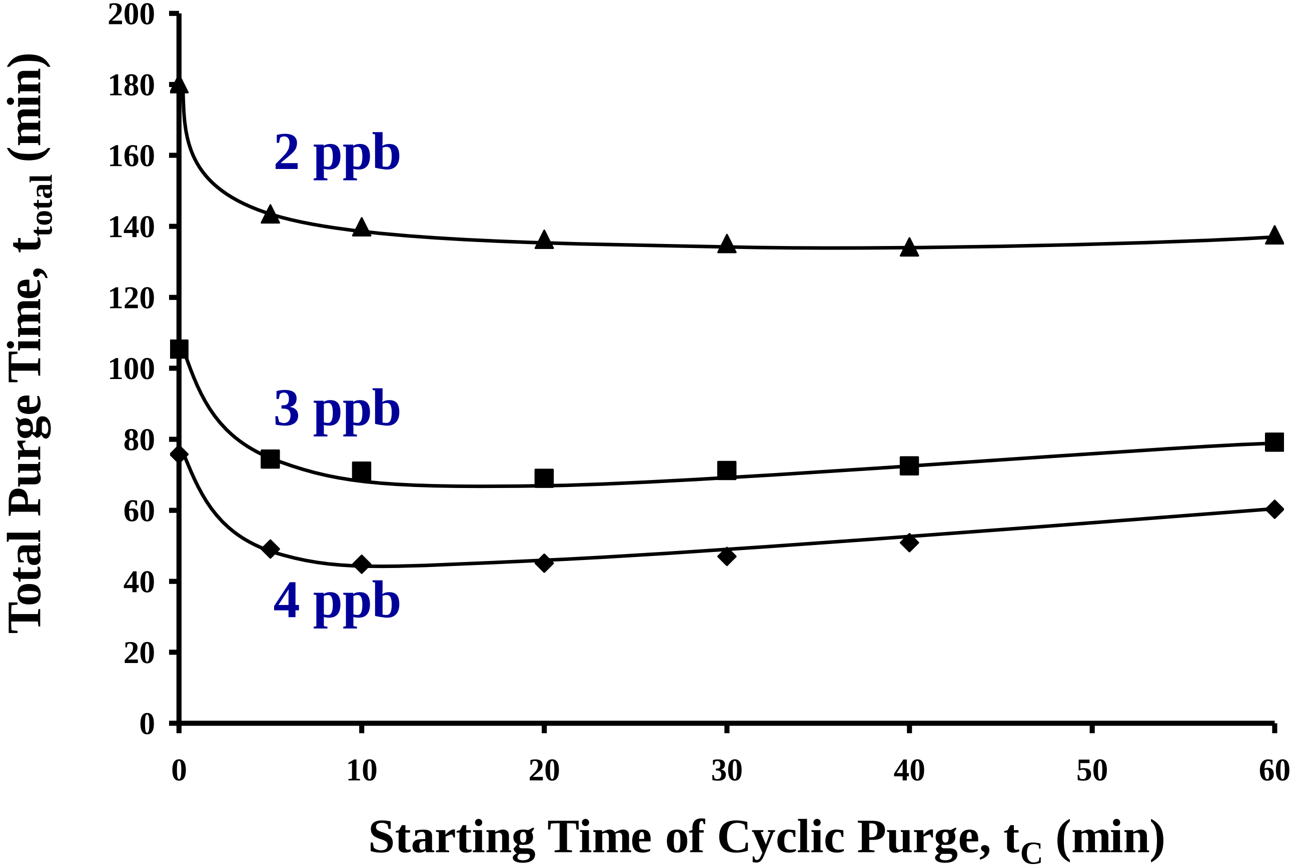
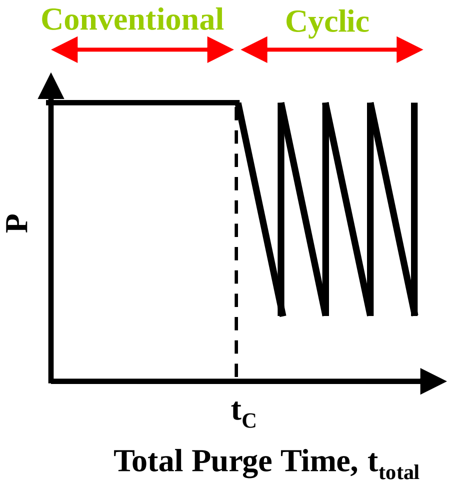
Optimum Starting Time of Cyclic Purge w/o Lateral

Pipe Length: 10 m, O.D.: 1.5 inch; initial conc.: 200 ppb





The starting time of cyclic purge needs to be optimized in order to minimize the total purge time

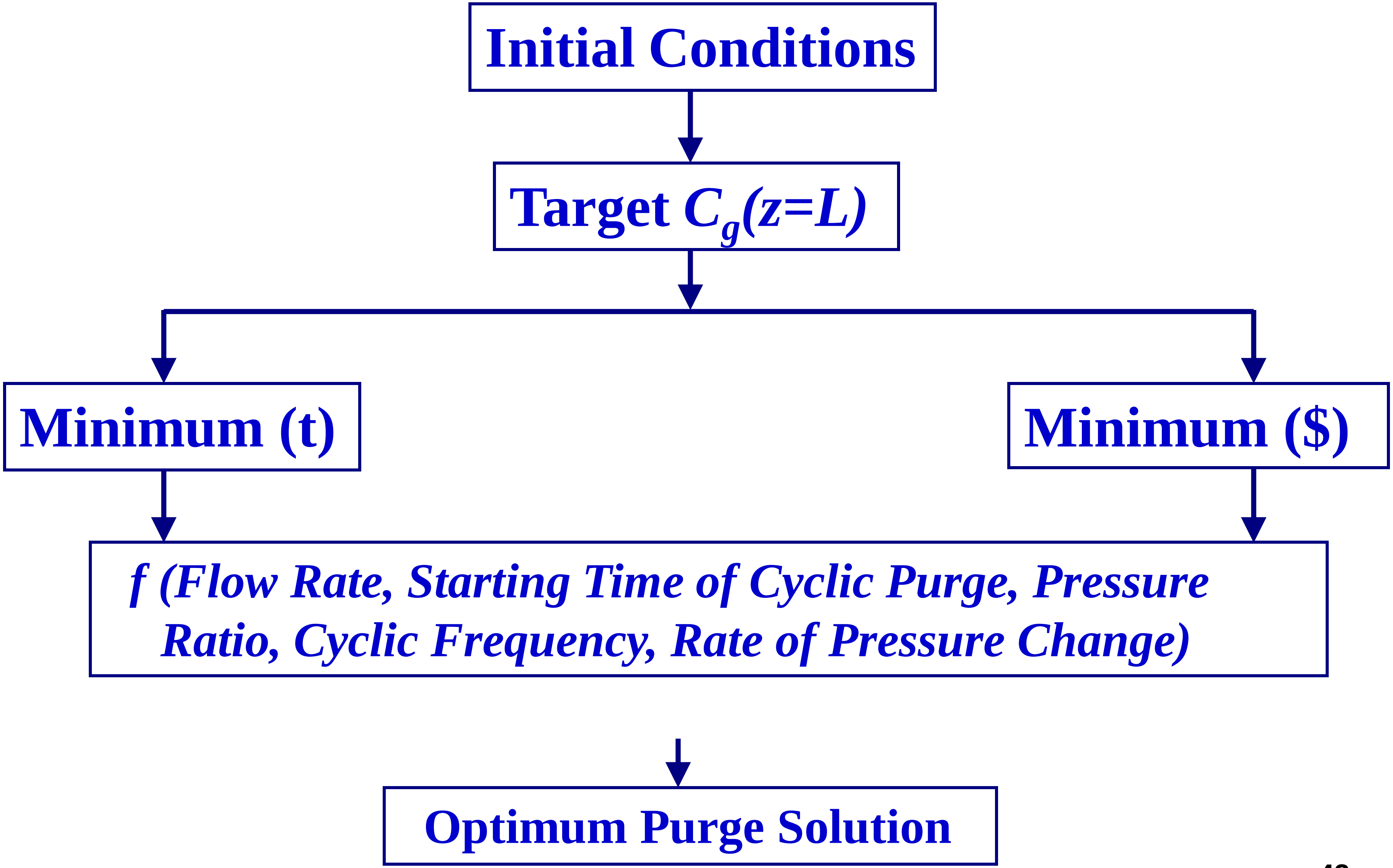
PCP vs. Normal Purge; Cyclic Purge Start Time Comparison

Start time for PCP has a noticeable affect on purge efficiency

System geometry effects optimum cyclic purge start time

The diversity of system geometries will make generating a heuristic quite challenging

Optimization of Purging Processes



Initial Conditions

Target $C_g(z=L)$

Minimum (t)

Minimum ($)

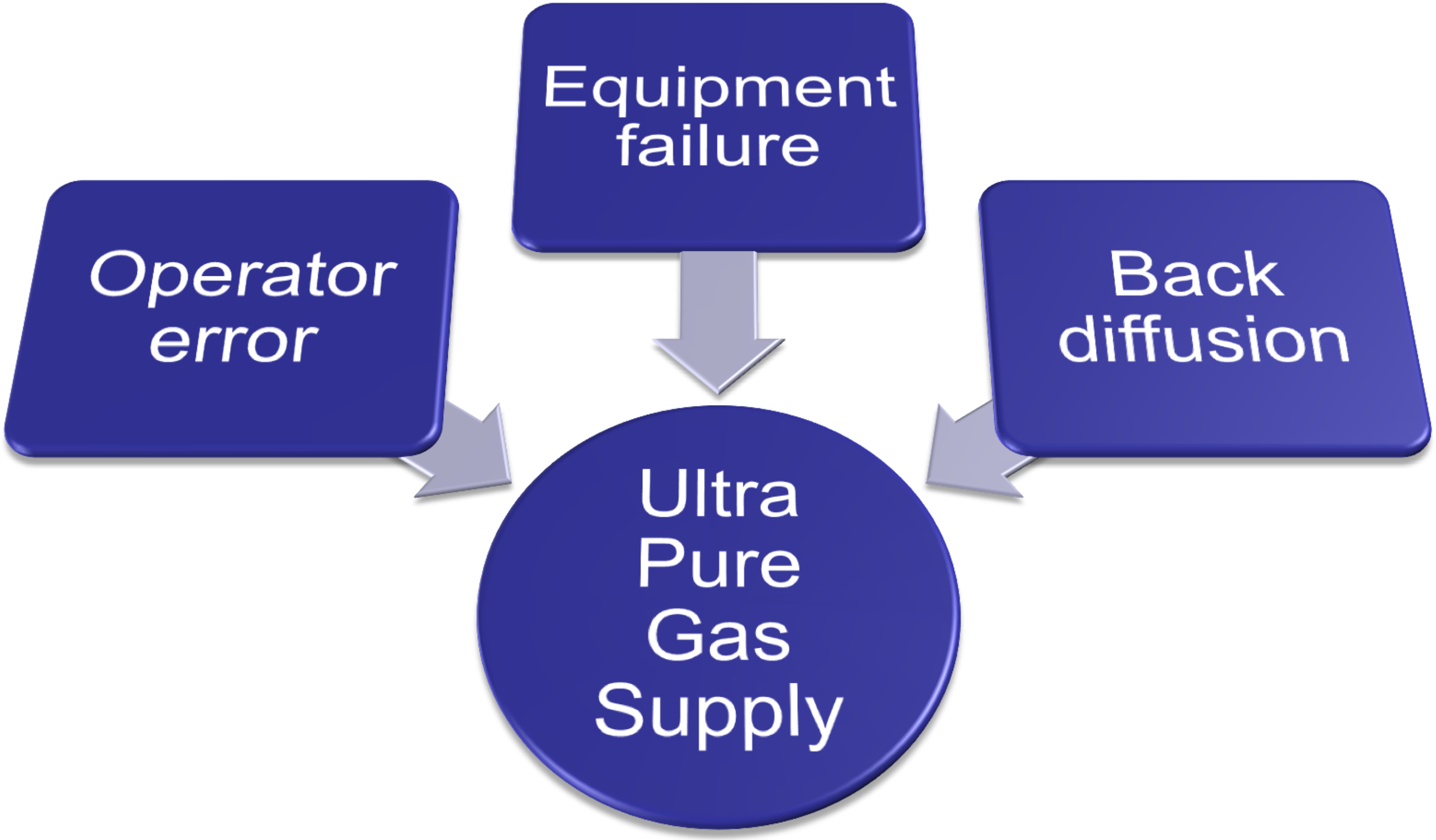
f (Flow Rate, Starting Time of Cyclic Purge, Pressure Ratio, Cyclic Frequency, Rate of Pressure Change)

Optimum Purge Solution

Highlights

- Compared with traditional purge with high system pressure and high purging gas flow rate, pressure cyclic purge takes less purging time and less purging gas usage in order to reduce moisture concentration down to an acceptable level.
- Pressure cyclic purge has a significantly greater impact in gas distribution systems with laterals than with system with no laterals.
- A user-friendly interface (including MATLAB) has been added to the simulator core program. This interface reduces the complexity of data input and facilitates simulator application by field engineers.
- Several companies have requested info on application of this simulator for their specific systems.

Examples of Contamination Sources



Equipment failure

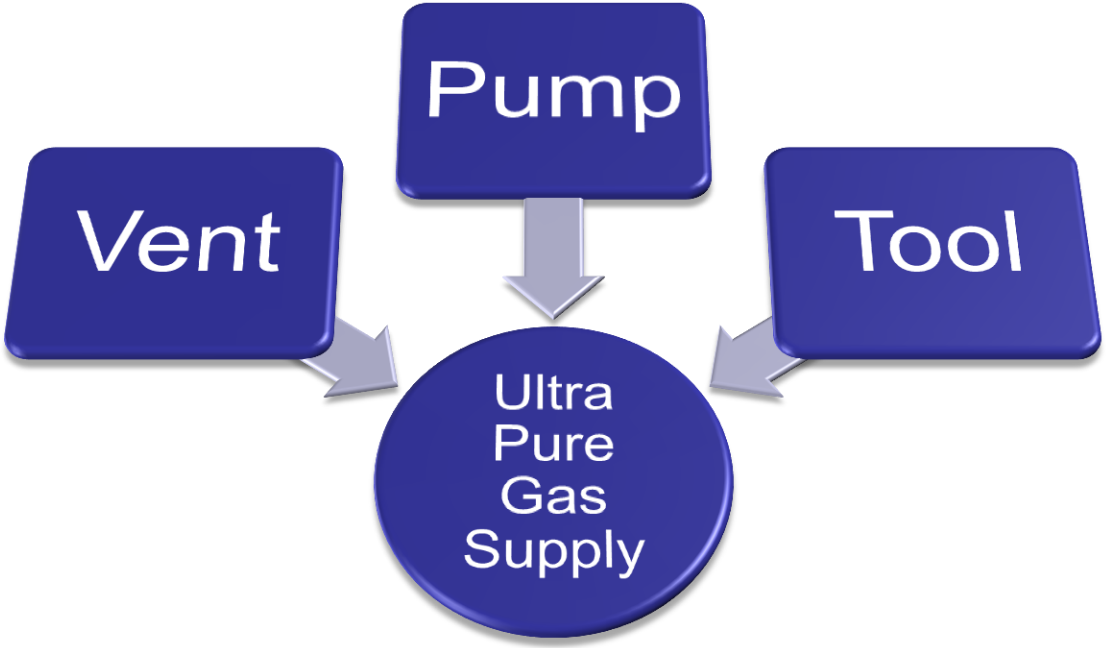
Operator error

Back diffusion

Ultra Pure Gas Supply

An understanding of back diffusion is necessary for minimizing contamination of the ultra pure gas distribution system

Back Diffusion Examples



Vent

Pump

Tool

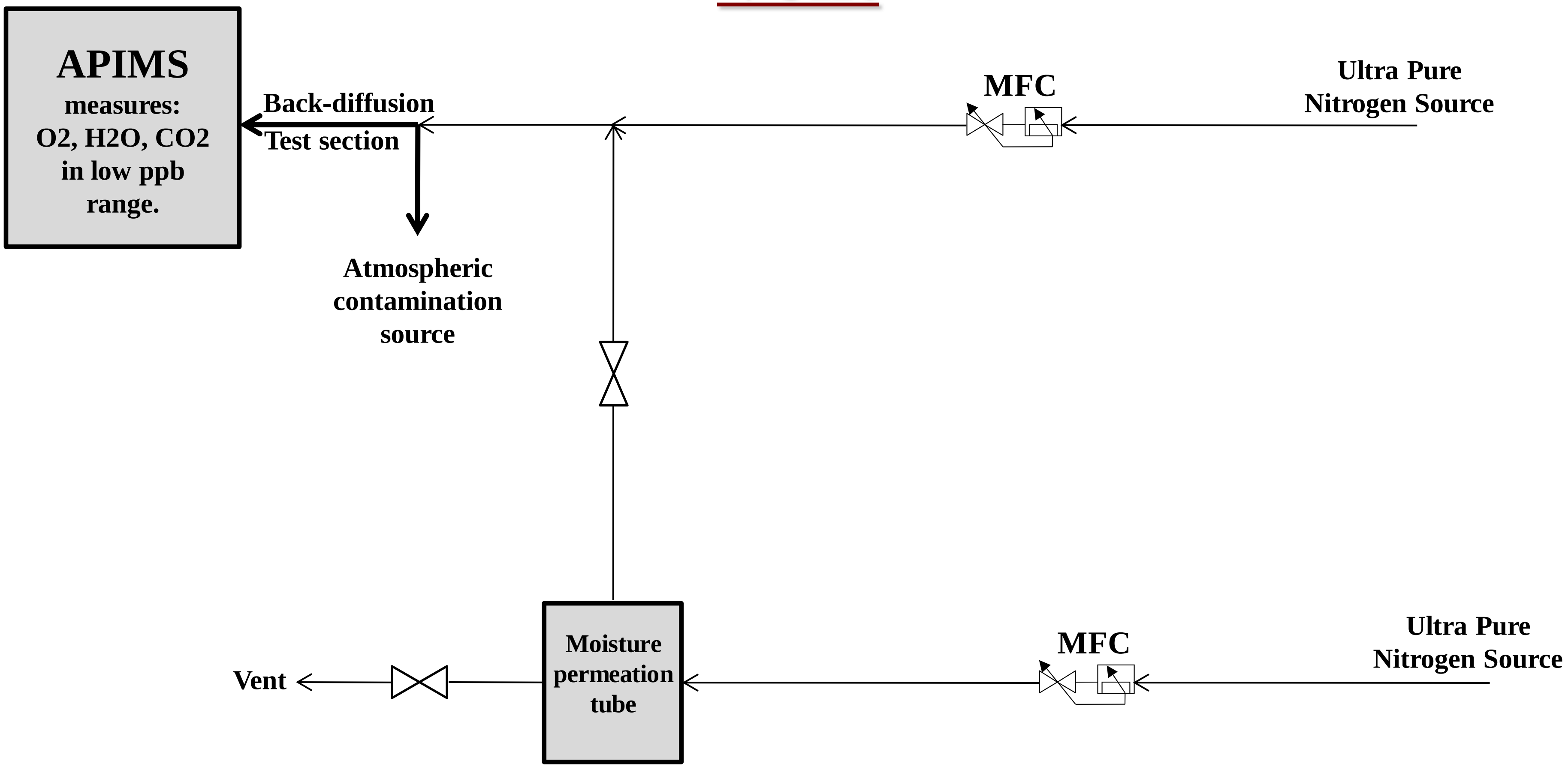
Ultra Pure Gas Supply

A

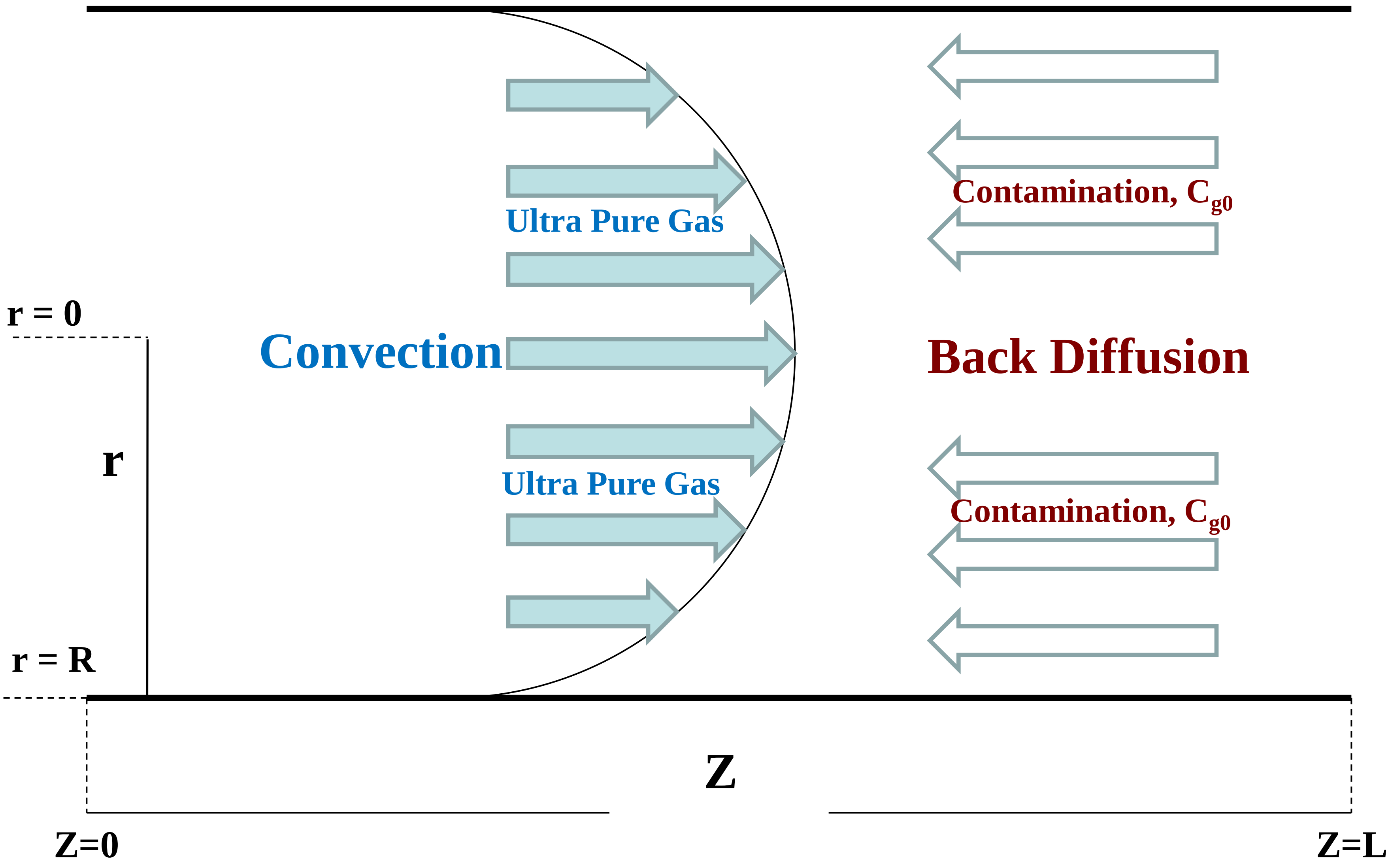
Mixture of A&B

B

Back Diffusion Experimental Setup; Vent



Back Diffusion Model Formulation



Back Diffusion Model Formulation:

In Gas Phase

$$\underbrace{2U_{avg}\left[1-\left(\frac{r}{R}\right)^2\right]\frac{\partial C_g}{\partial z}}_{\text{Laminar Convective Flow}}+\underbrace{D_g\frac{\partial^2 C_g}{\partial z^2}}_{\text{Axial Diffusion}}+\underbrace{\frac{D_g}{r}\frac{\partial}{\partial r}\left(r\frac{\partial C_g}{\partial r}\right)}_{\text{Radial Diffusion}}=0$$

Boundary Conditions

$$C_g = C_{g0} \quad at\ z = 0,\ \ 0 \le r \le R$$

$$C_g = C_{g-} \quad at\ z = L,\ \ 0 \le r \le R$$

$$\frac{\partial C_g}{\partial r} = 0 \quad at\ r = 0,\ \ 0 \le z \le L$$

$$-D_g\frac{\partial C_g}{\partial r} = k_a C_g - k_d C_s \quad at\ r = R,\ \ 0 \le z \le L$$

Back Diffusion Model Formulation:

On Surface

$$\underbrace{D_s \frac{d^2 C_s}{dz^2}}_{\textbf{Surface Diffusion}} + \underbrace{k_a C_{g_{r=R}} - k_d C_s}_{\textbf{Adsorption and Desorption}} = 0$$

Boundary Conditions

$$C_s = \frac{k_a}{k_d} C_g \quad at\ z = 0$$

$$C_s = \frac{k_a}{k_d} C_{g-} \quad at\ z = L$$

Future Work on Back Diffusion

Experiments

- Generate data

Model

- Fit model to data
- Perform parametric studies

Optimization

- Minimize contamination
- Minimize resource usage

Interactions

- Continue working with Intel on finalizing the simulator for field applications
- Study the effect of contaminants back-streaming from tools and other sources; develop strategies to minimize gas usage for preventing back-streaming

Presentations and Papers

- Lowering Material and Energy Usage during Purging Ultra-High-Purity Gas Distribution Systems (presenter), AIChE 2009 Annual Meeting, Nov. 2009, Nashville, Tennessee.
- Application of Pressure Cyclic Purge (PCP) in Dry-down of Ultra-High-Purity Gas Distribution Systems, published in *Chemical Engineering Sciences*

Acknowledgements

- Val Strazds, Intel
- Tiger Optics LLC