Pressure Swing Absorption Device and Process for Separating CO_2 from Shifted Syngas and its Capture for Subsequent Storage

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- **Technology Description**

(a) **Process and Device Concept**

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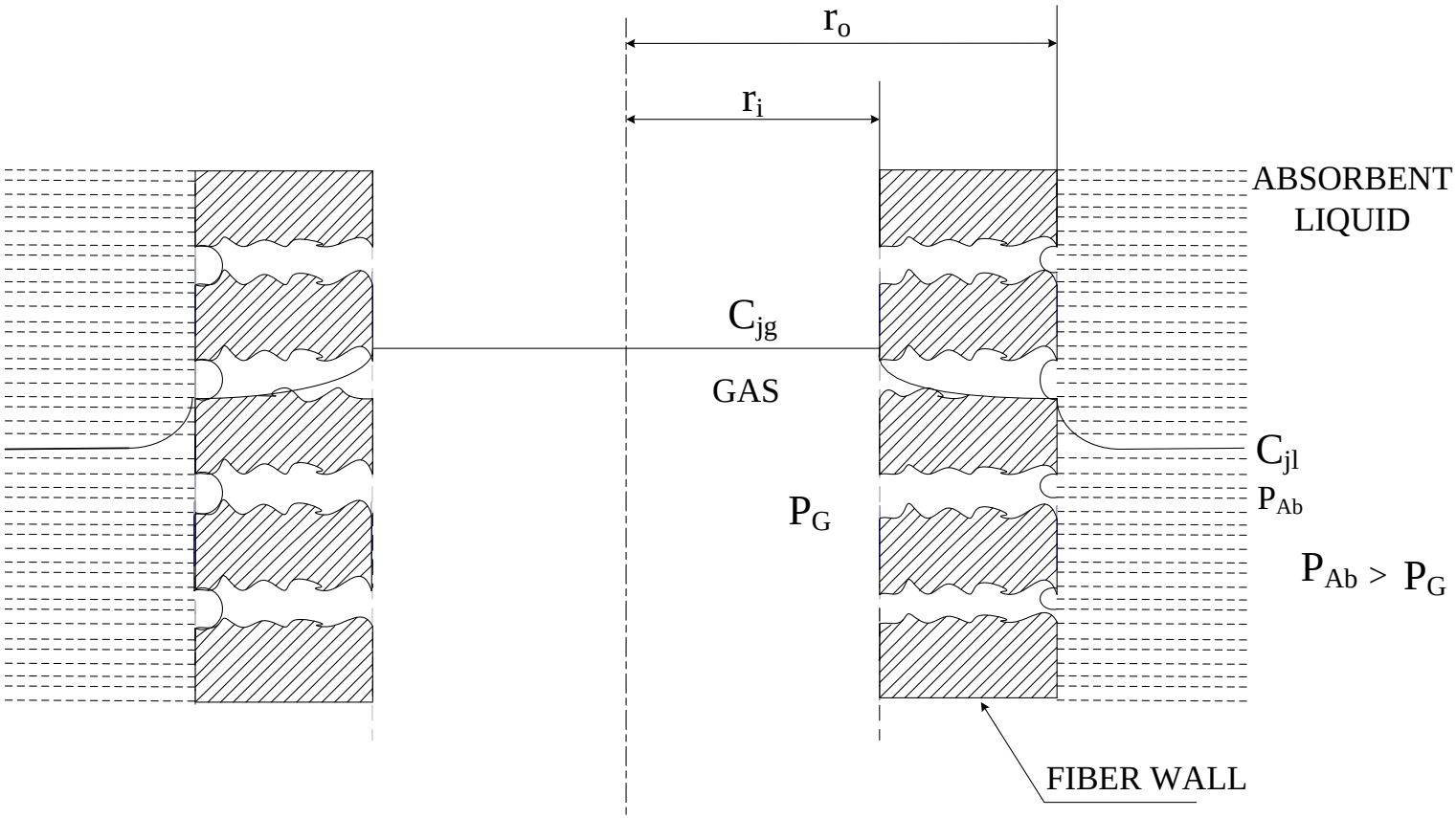
Pressure swing absorption of CO_2 for post **low-temperature** shift reactor gas using membrane contactors containing ionic liquids, dendrimers etc.

Concentration profile for absorbed species in gas and liquid phases in a membrane contactor



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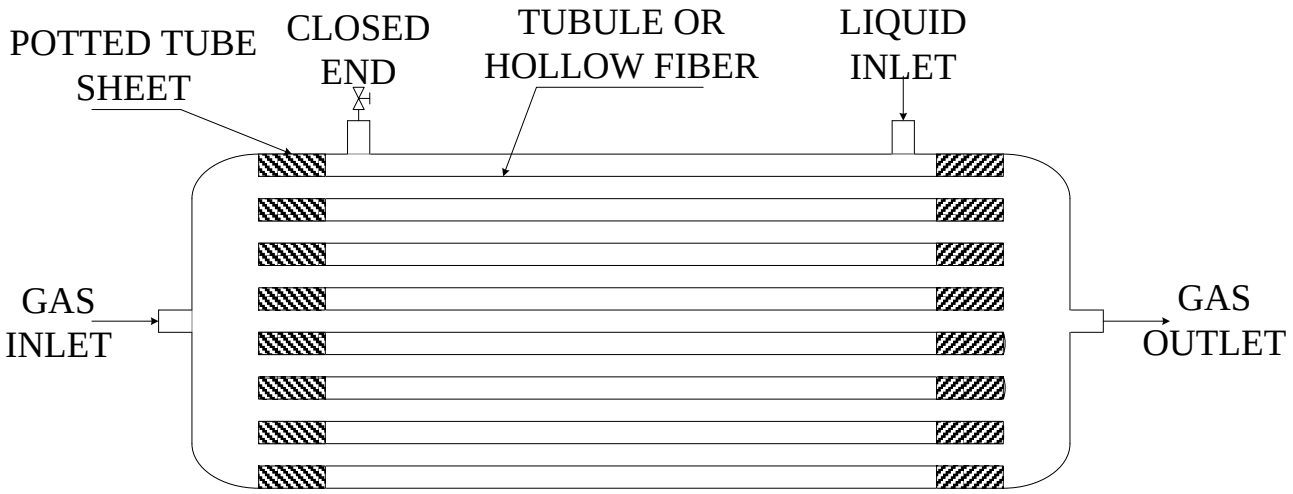
Schematic of the absorber containing ceramic tubules or hollow fibers



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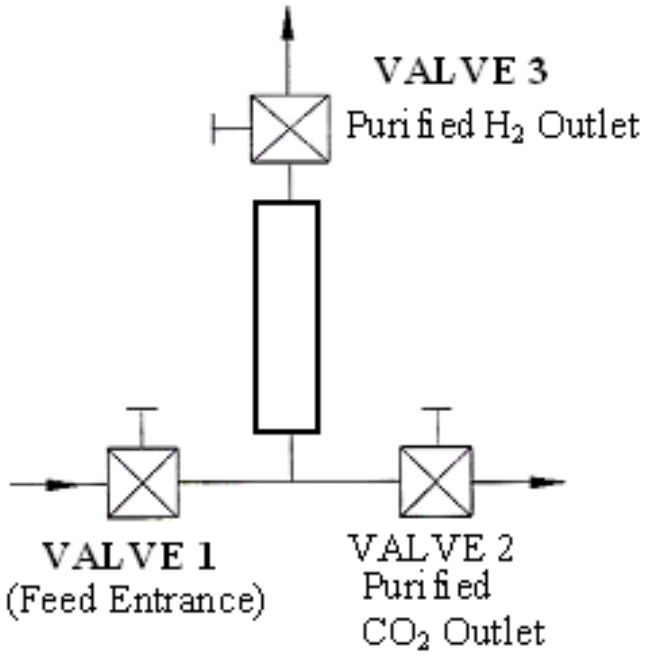
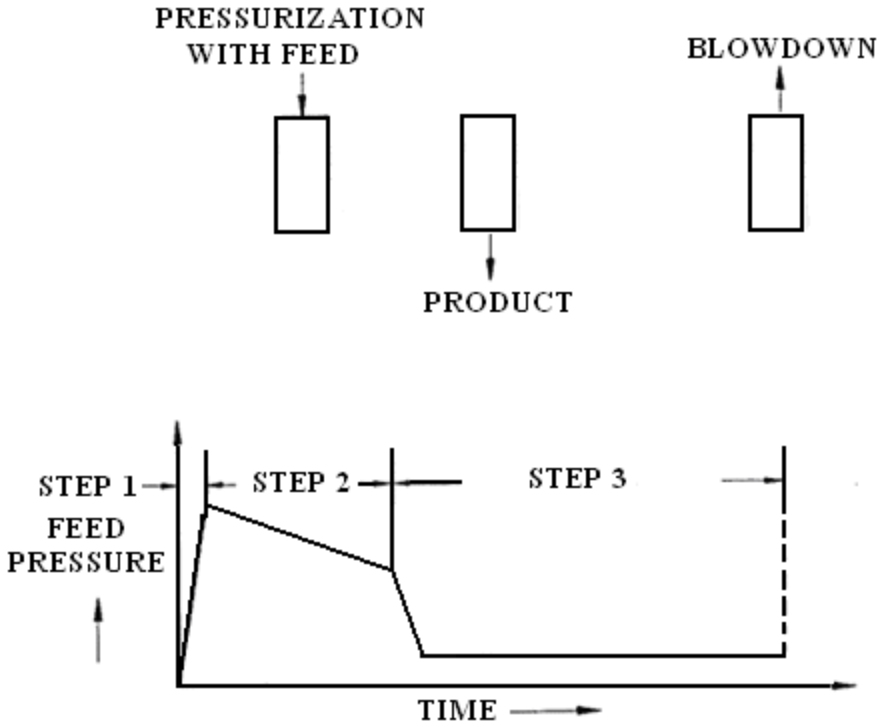
Pressure Swing Absorption Operation



Solenoid Valve Locations in Pressure Swing Absorption (PSAB) Apparatus



Pressure vs. time profile in the bore of tubule or hollow fiber in PSAB

(Bhaumik et al., *AIChE J.*, 42, 409-421 (1996))

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Pressure Swing Absorption (PSAB) in a Membrane Contactor Device

- Basic separation concept implemented with 10% CO_2-90% N_2 gas mixture at 375 kPa and 19.5 wt% aqueous DEA solution (RAPSAB – Rapid Pressure Swing Absorption)

- Its adaptation to the current problem of treating low temperature post-shift reactor synthesis gas at ~20 atm and 150-180^{0}C

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Potential Advantages of the Proposed Separation Technique-1

- Has high solubility selectivity of novel selected liquid absorbents having relatively high viscosity
- Has high purification ability of pressure swing adsorption process
- Has high gas-liquid contacting surface area per unit device volume
- Has a compact membrane-like device
- Scale up should be easier due to modularity of membrane-based devices and membrane-based phase contacting

Potential Advantages of the Proposed Separation Technique-2

- Will deliver highly purified H_2 at nearly its partial pressure and temperature in the post-shifted reactor synthesis gas feed

- Purified CO_2 stream will be available at ~1atm

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Nonvolatile Absorbents for PSAB

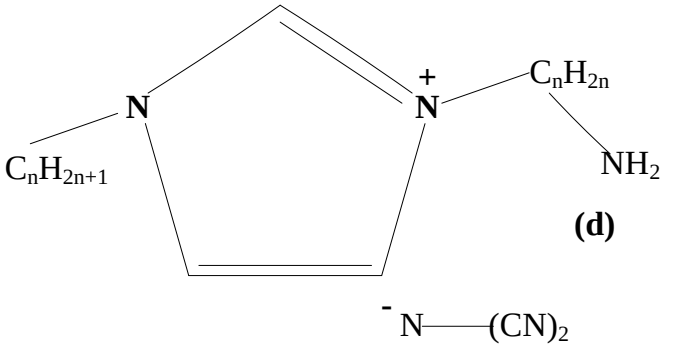
1. Ionic Liquids:

$[bmim]^+[PF_6]^-$ (Fluka)

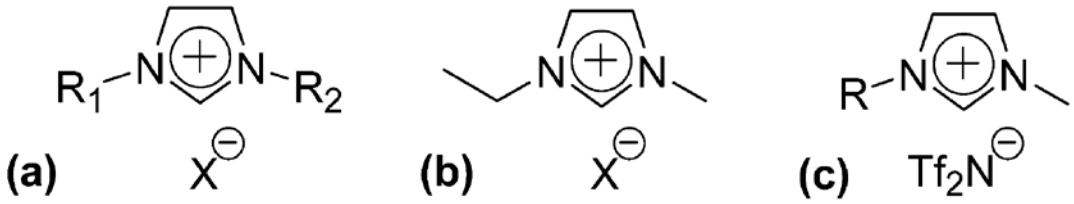
$[bmim]^+[DCA]^-$ (Merck)

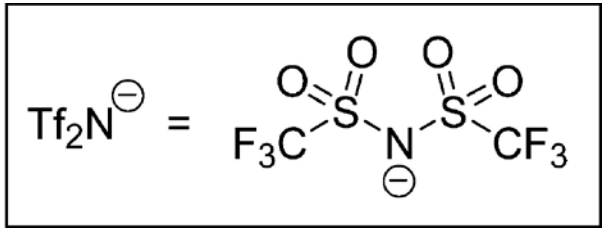
$[Am\text{-}Im]^+[DCA]^-$ (Functionalized)

(with or without moisture)



(d) Functionalized IL structure for $[Am\text{-}Im]^+[DCA]^-$





General structures of (a) imidazolium-based RTILs, (b) $[C_2mim][X]$ RTILs, and (c) $[Rmim][Tf_2N]$ RTILs. (Bara et al., *Ind. Eng. Chem. Res.*, 48, 2739 (2009))

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Nonvolatile Absorbents for PSAB

2.(a) Dendrimers/hyperbranched polymers of lower molecular weight:

Polyamidoamine (PAMAM) generation 0, MW-516, 4 primary amines, 2 tertiary amines;

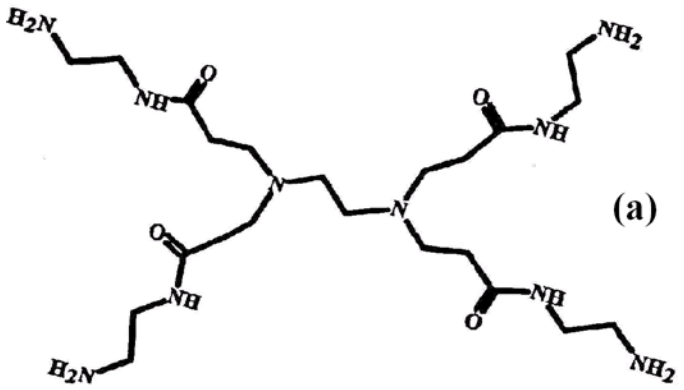
Generation 2, MW-3130

(Dendritech, Midland, MI)

Use in a nonvolatile solvent,

such as polyethylene glycol (PEG 400)

Highly reactive in the presence of moisture



(a) PAMAM dendrimer of generation 0

(1. Kovvali et al., *JACS*, 122 (31) 7594 (2000); 2. Kovvali and Sirkar, *I&E C Res.*, 40(11), 2502 (2001); 3. Kosaraju et al., *I&E C Res.*, 49, 1250 (2005))

(b) Polyethyleneimines of lower molecular weight, Lupasol FG (BASF), MW-615

(Rolker et al., *I&E C Res.*, 46, 6572 (2007)

Adaptation of PSAB Device to the Current Problem

1. Porous PP membrane substrate replaced by hydrophobized porous ceramic tubules, porous PTFE hollow fibers and hydrophobized PEEK hollow fibers (higher temperature, wettability considerations)
2. High pressure means smaller membrane pore size (5 nm to 10 nm) at the gas-liquid interface to prevent any phase breakthrough
3. Longer length of hollow fibers in RAPSAB replaced by number of modules of hollow fiber/ceramic tubules in series (limitation of oven dimensions)

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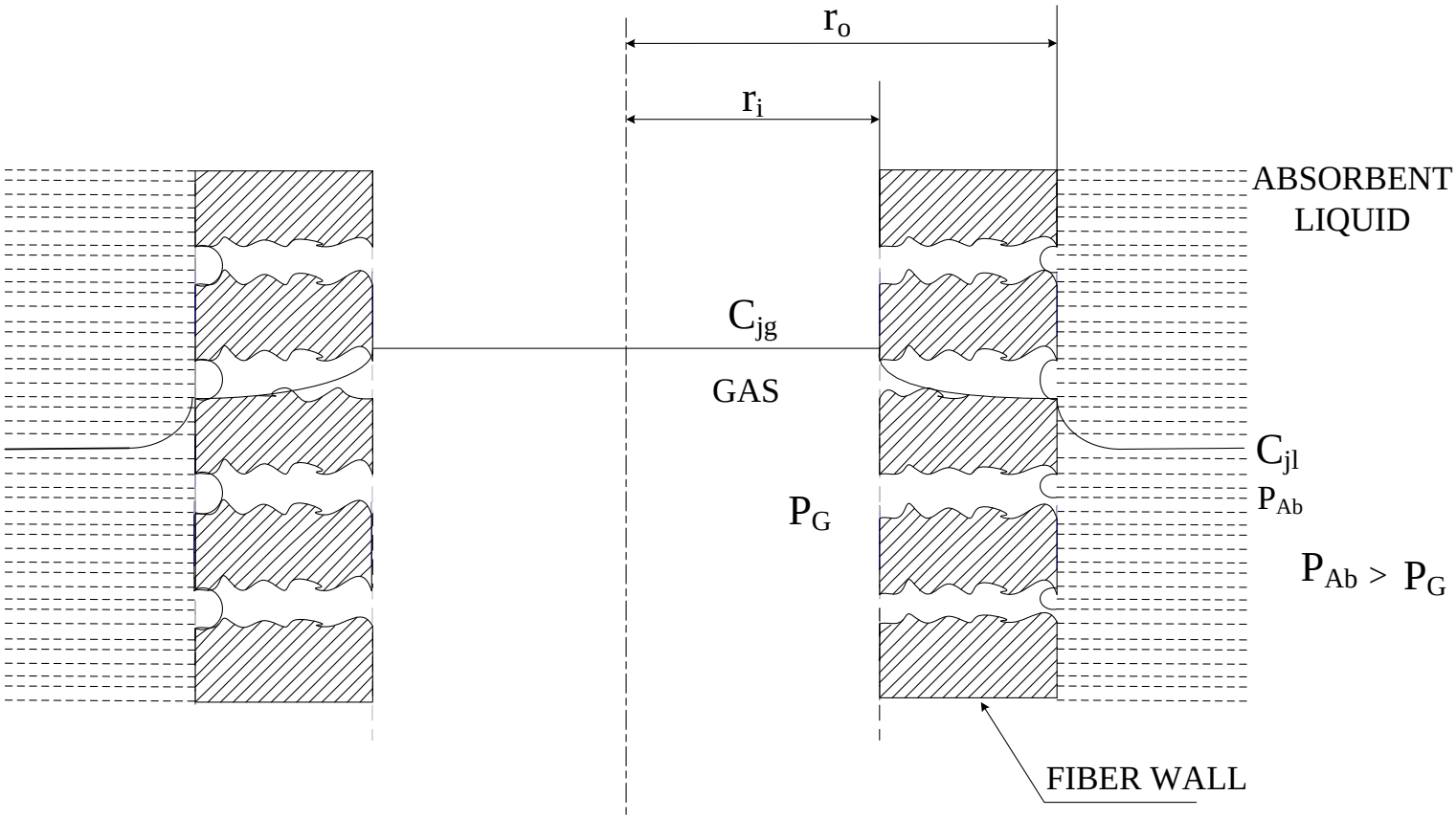
Concentration profile for absorbed species in gas and liquid phases



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Breakthrough pressure for a nonwetted pore size of radius r_p (Young-Laplace Equation)

$$\Delta P_{breakthrough} \cong \frac{2\gamma \cos\theta}{r_p}$$

Increase γ , decrease r_p

The pores should remain nonwetted.

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Nondisperssive Gas Absorption/Stripping Requires Nonwetted Pores

1. To prevent spontaneous pore wetting

   Surface tension of absorbent liquid

   $\gamma > \gamma_{critical}$ of the polymeric coating

2. $\gamma_{critical}$ of fluoropolymers, C_{18} surfaces….15-20 dyne/cm
3. Absorbent liquids under consideration have considerably higher γ values; γ will fluctuate due to absorption and desorption of moisture

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- **Ceramic Tubules:**

  1.5 mm I.D., 3.8 mm O.D. γ-alumina coating on alpha-alumina substrate hydrophobized with nonafluorohexylsilane coating

  Pore radius ~5 nm <0.03µm , 940 m^2/m^3 surface area/device volume

  For say, a 40 dyne/cm liquid to withstand 20 atm+, 10 nm pore size

  C_{18} hydrophobic coatings and epoxy-based tube sheet up to 200^0C

(Media and Process Technology, Pittsburgh, PA; Rich Ciora/Paul K.T. Liu)

- **Teflon Hollow Fibers:**

  0.53 mm I.D., 1.08 mm O.D. Pore size <0.1µm

  Plasma polymerize a nanoporous fluorosilicone coating to reduce the pore size to ≤0.01µm

(Applied Membrane Technologies, Inc., Minnetonka, MN; Stephen Conover)

- **PEEK Hollow Fibers:**

  300 µm I.D., 500 µm O.D., porous hollow fibers of poly (ether ether ketone), hydrophobized surface via fluorination of the surfaces

(Porogen Inc., Woburn, MA; Ben Bikson)

CO_2 Gas-Liquid/Liquid-Gas Mass Transfer Aspects

- Stagnant highly viscous absorbent liquid on the shell side
- Tube-side flowing gas present in pores of membrane

$$\textit{Rate of physical gas absorption} \quad \alpha \quad \sqrt{\frac{D_{CO_2}}{\pi t}}$$

$$\textit{Amount absorbed per unit area} \quad \alpha \quad \sqrt{\frac{D_{CO_2} t}{\pi}}$$

$$D_{CO_2} \quad \alpha \quad \frac{1}{\mu_{absorbent}}$$

- High temperature of operation will reduce $\mu_{absorbent}$ drastically

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Gas Mixture to be Studied

- 45% He, 30% CO_2, Rest being H_2O
- ~150^0C, 200-300 psig
- Helium as a surrogate for H_2

- Typical Gasifier Composition:

  ~38% H_2, 29% CO_2, 33% H_2O, 0.15% CO

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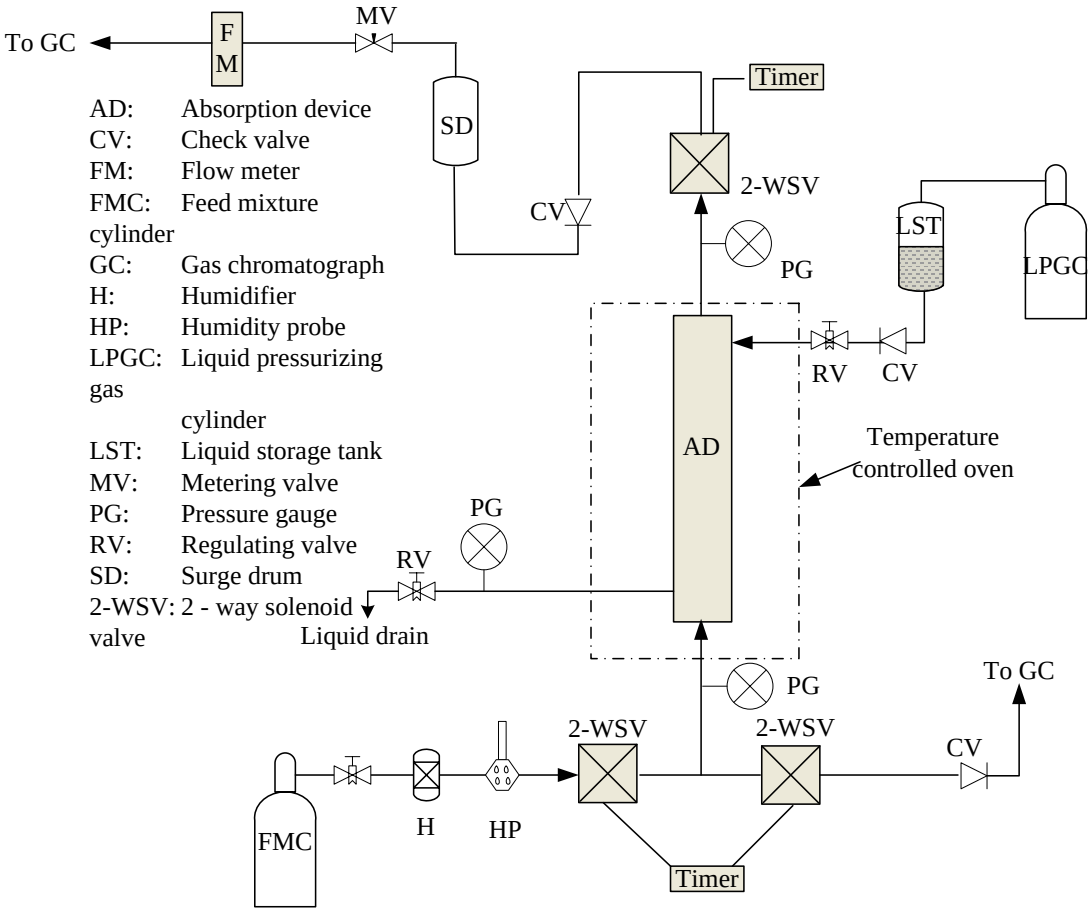
Schematic of the experimental setup for pressure swing absorption



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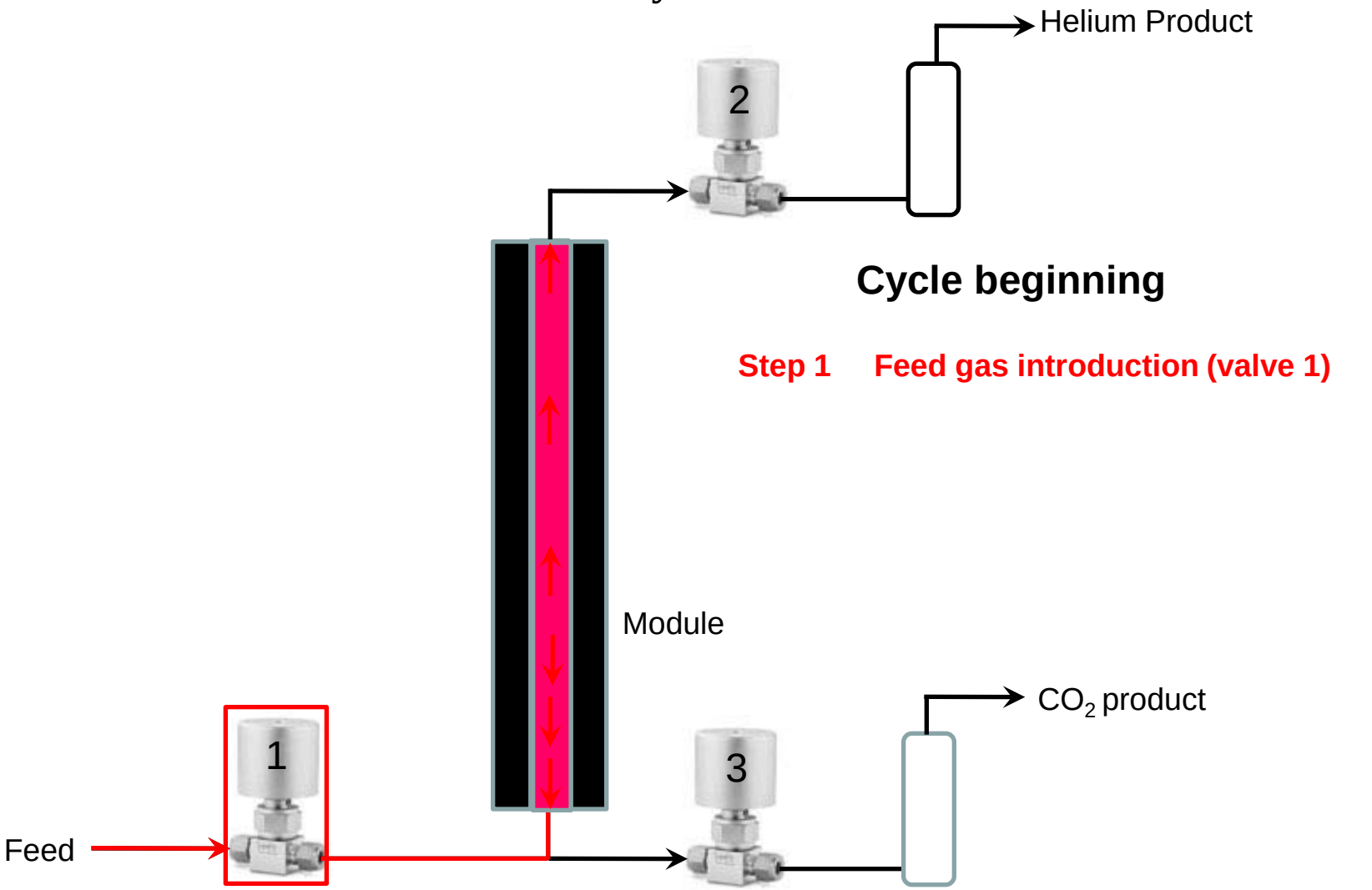
Process of pressure swing absorption for separating CO_2 from shifted syngas: 3-Valve system



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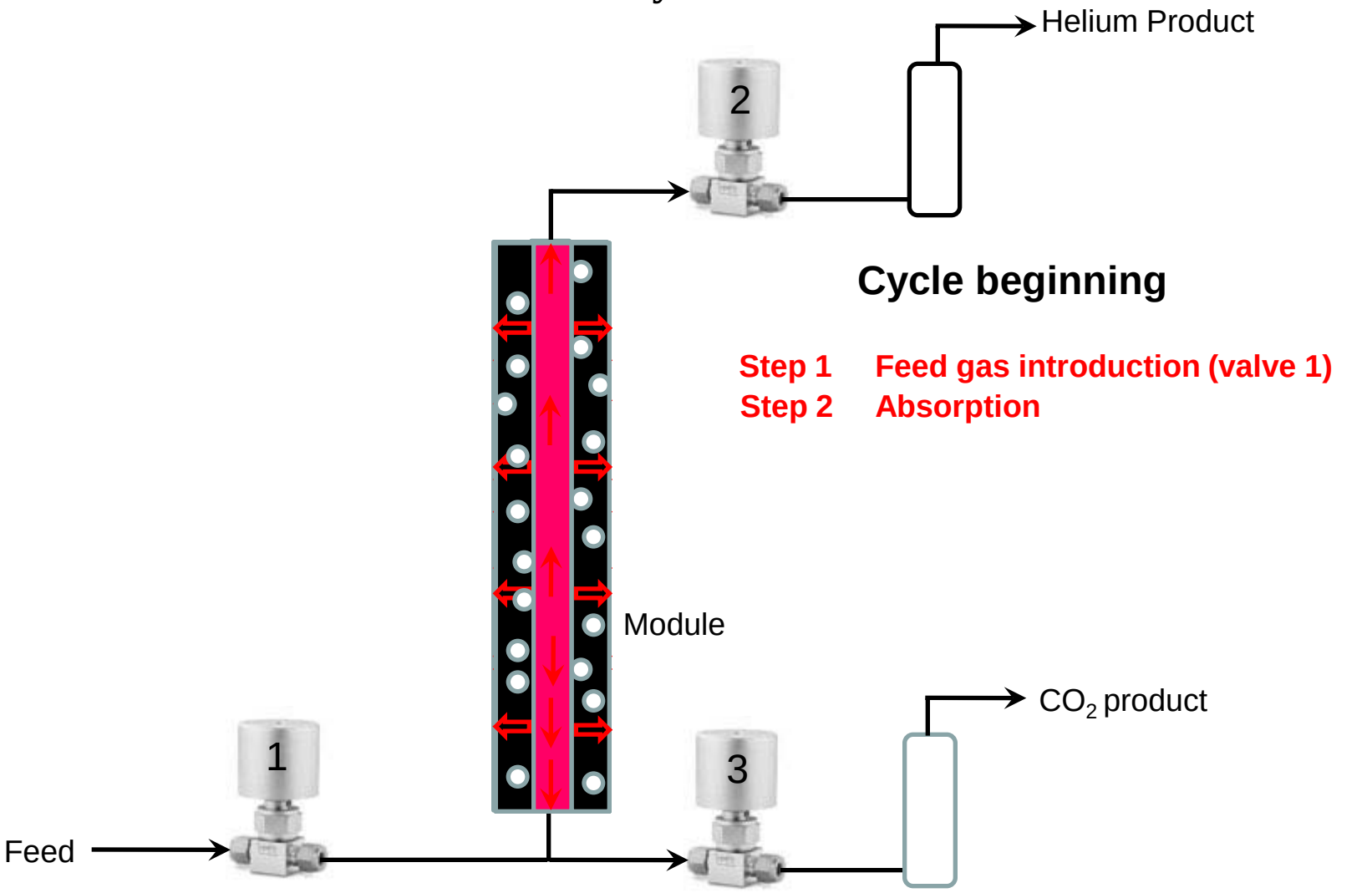

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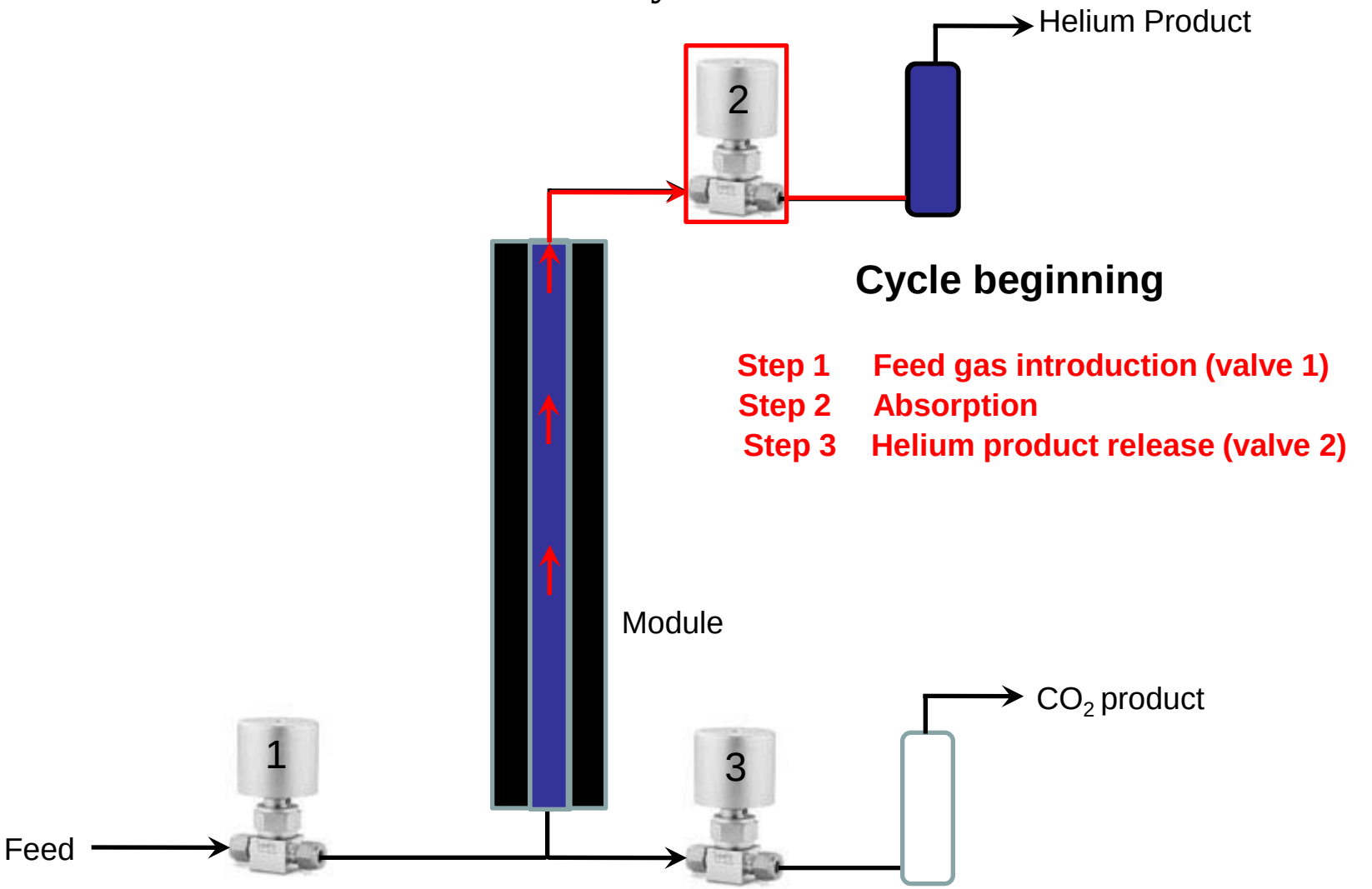

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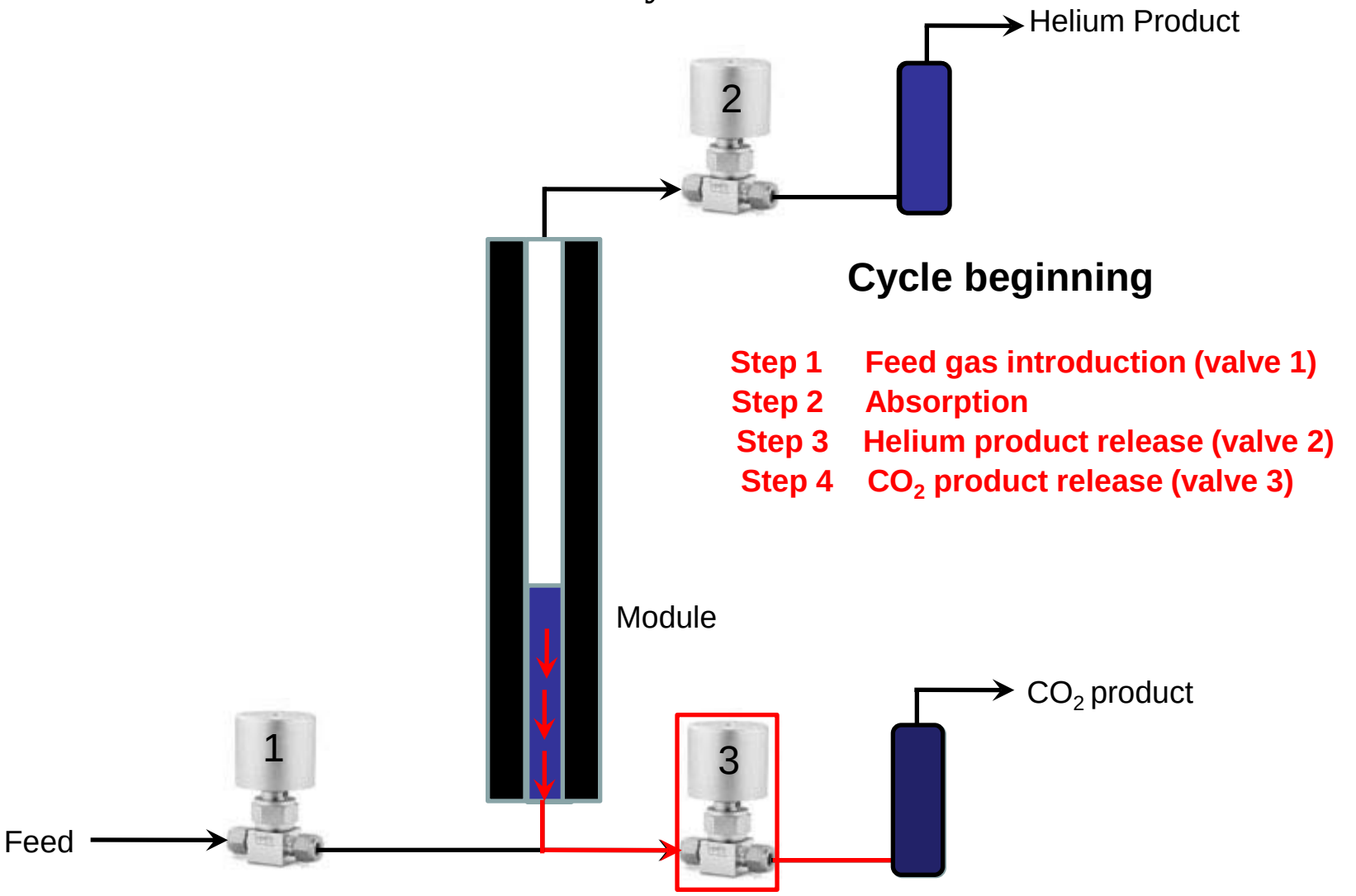

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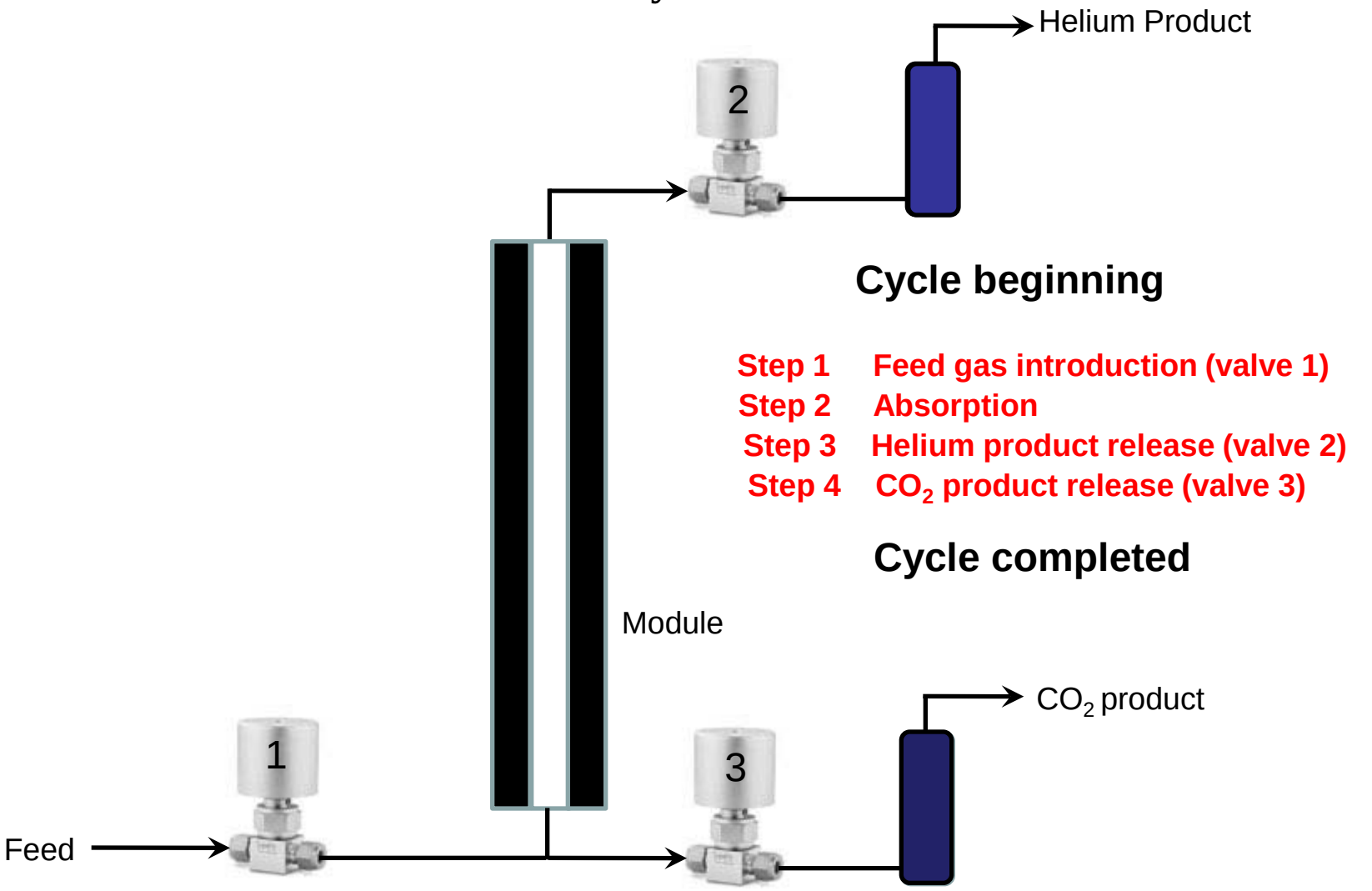

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Project Objectives

- Develop via laboratory experiments an advanced pressure swing absorption-based device and a cyclic process to produce purified helium (a surrogate for hydrogen) at a high pressure for IGCC-CCS plant's combustion turbine from low temperature post-shift reactor synthesis gas and simultaneously obtain a highly purified CO_2 stream containing at least 90% of the CO_2 in the post-shift reactor gas stream and suitable for subsequent sequestration

- Provide data and analysis of the cyclic process and device to facilitate subsequent scale up

- Develop a detailed analysis for the process and device to allow economic evaluation for potential larger-scale use

Project Objectives: PHASE-I

I1. Develop an experimental setup for studying the PSAB process

I2. Develop novel gas-liquid absorption modules employing ceramic tubules and polymeric hollow fibers of PTFE and PEEK

I3. Initiate preliminary studies of pressure swing absorption-based separation of a moist CO_2-He gas mixture at 150^0C and 200-300 psig simulating a low temperature post-shift reactor synthesis gas stream

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Project Objectives: PHASE-II

II1. Study the performance of the PSAB process for selected absorbents vis-à-vis purification of the feed gas stream to obtain a high pressure purified He stream and a low pressure purified CO_2 stream

II2. Develop experimental setups to measure the solubility and diffusion coefficients of CO_2 and He at the appropriate ranges of temperature and pressure for selected absorbents

II3. Initiate development of a mathematical model of the PSAB device and process

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Project Objectives: PHASE-III

III1. Generate experimental data on the solubility and diffusion coefficient for CO_2 and He for the selected absorbents

III2. Compare the results of simulation of the mathematical model with the observed purification and separation in the PSAB process and device for selected absorbents

III3. Perform simulations of the model to explore scale up of the process to facilitate evaluation of the process

III4. Determine the extent of loss/deterioration of the absorbents over extended periods of operation

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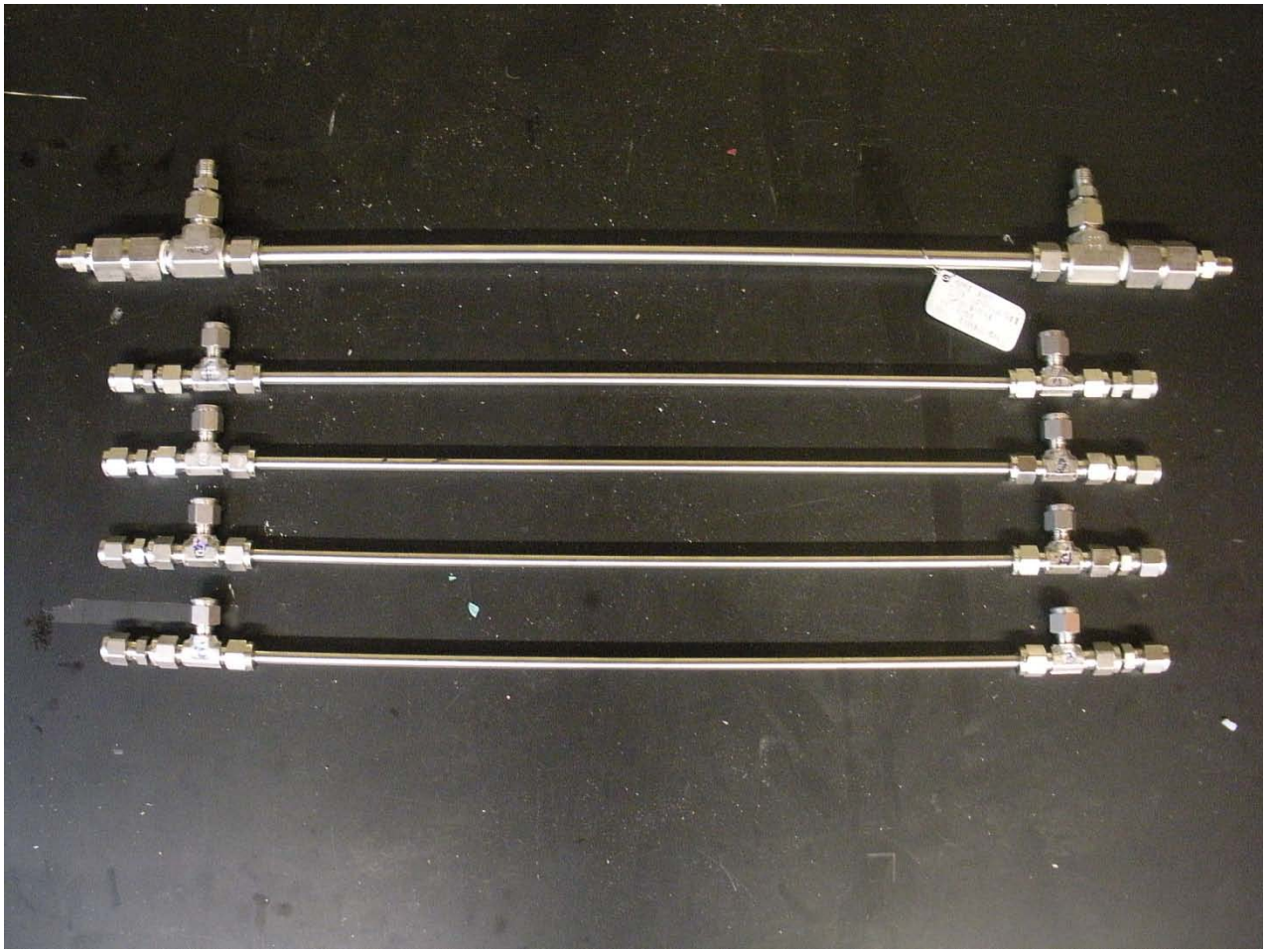
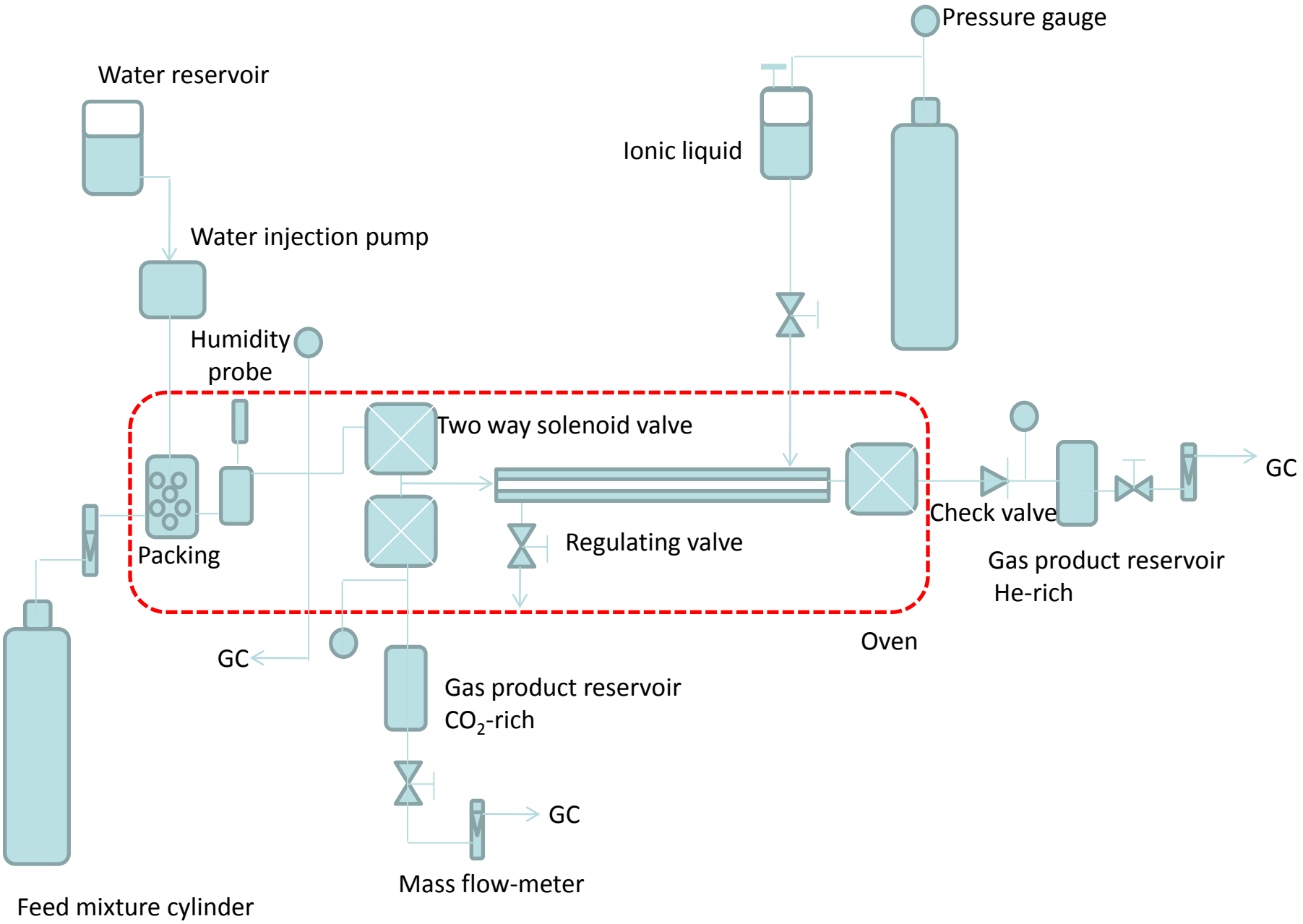
Details of Membrane Modules (Phase I)

Membrane module type	Details of Membrane Modules					
	I.D. mm	O.D. mm	Pore Size µm	No. of fibers/tubules	Length	Shell Diameter
*Ceramic membrane modules # 1,2,3,4	1.5	3.8	0.005	1	18”	1/4 “ OD 0.035” wall thickness
Teflon hollow fiber module (epoxy potting)	0.53	1.08	~ 0.01	18	18”	3/8” OD .035” wall thickness
PEEK hollow fiber module (epoxy potting)	0.25	0.45	~ 0.01	240	18”	¼”

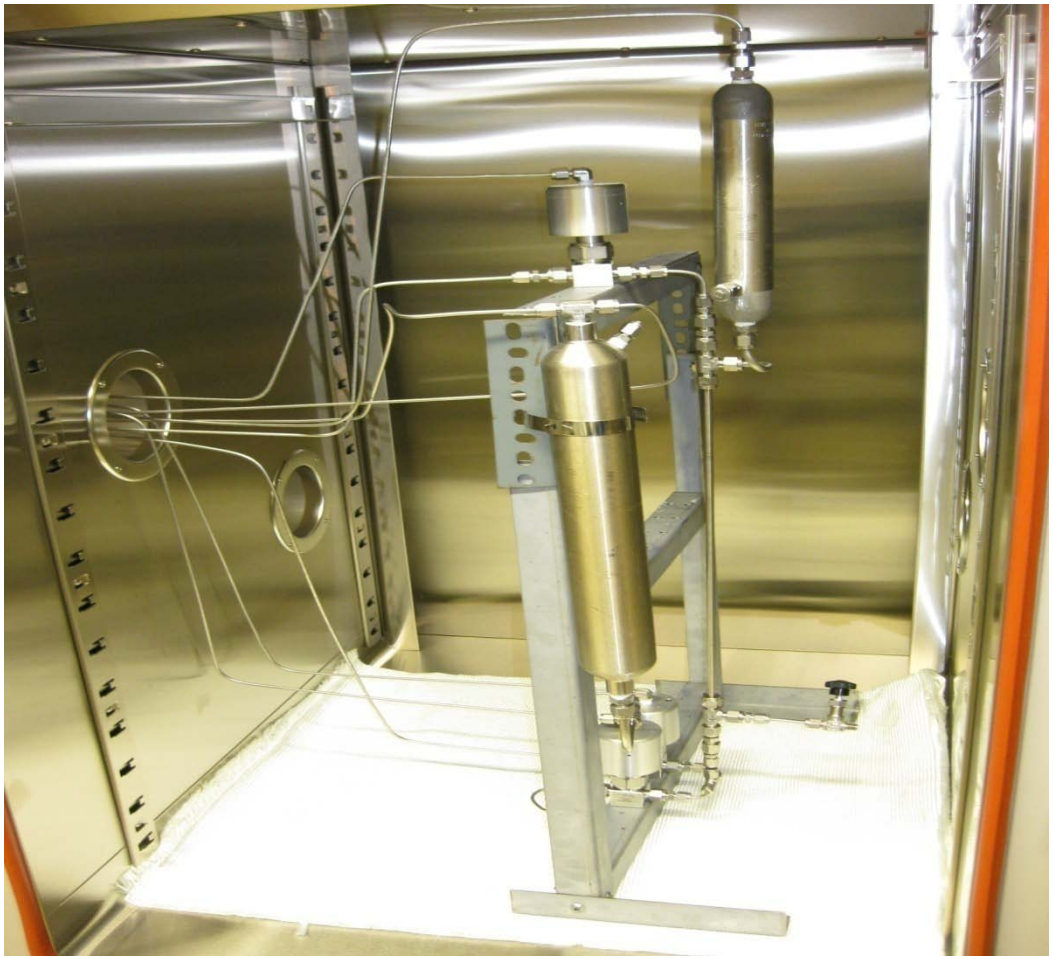
* Single ceramic tubule, ‘o’-ring seal.

Module with Teflon Hollow Fibers and 4 Modules containing Ceramic Membrane Tubules



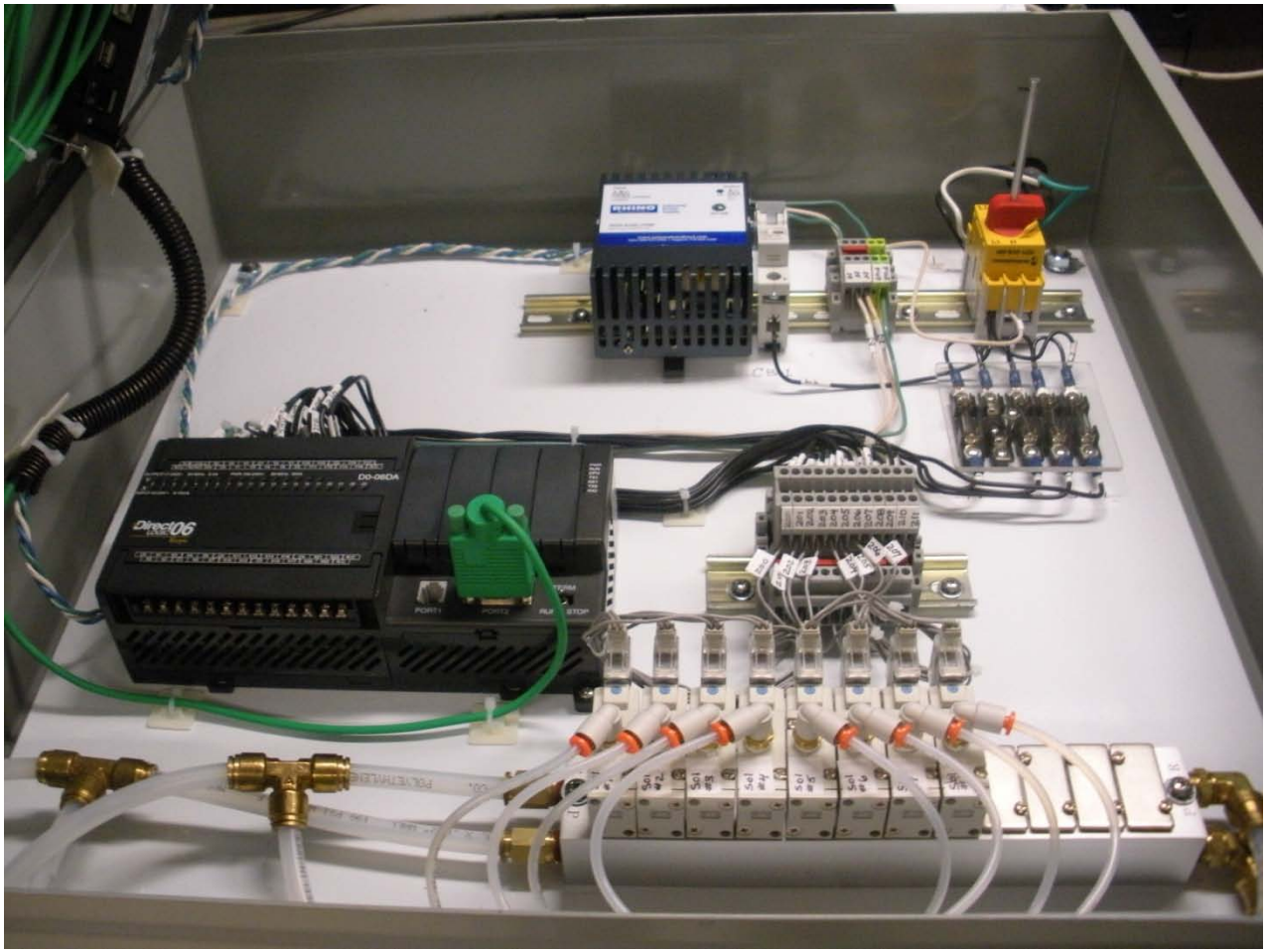

Pressure gauge
Water reservoir
Ionic liquid
Water injection pump
Humidity probe
Two way solenoid valve
GC
Packing
Regulating valve
Check valve
Gas product reservoir
He-rich
Oven
GC
Gas product reservoir
CO_2-rich
GC
Mass flow-meter
Feed mixture cylinder

Experimental Setup inside the Oven for PSAB

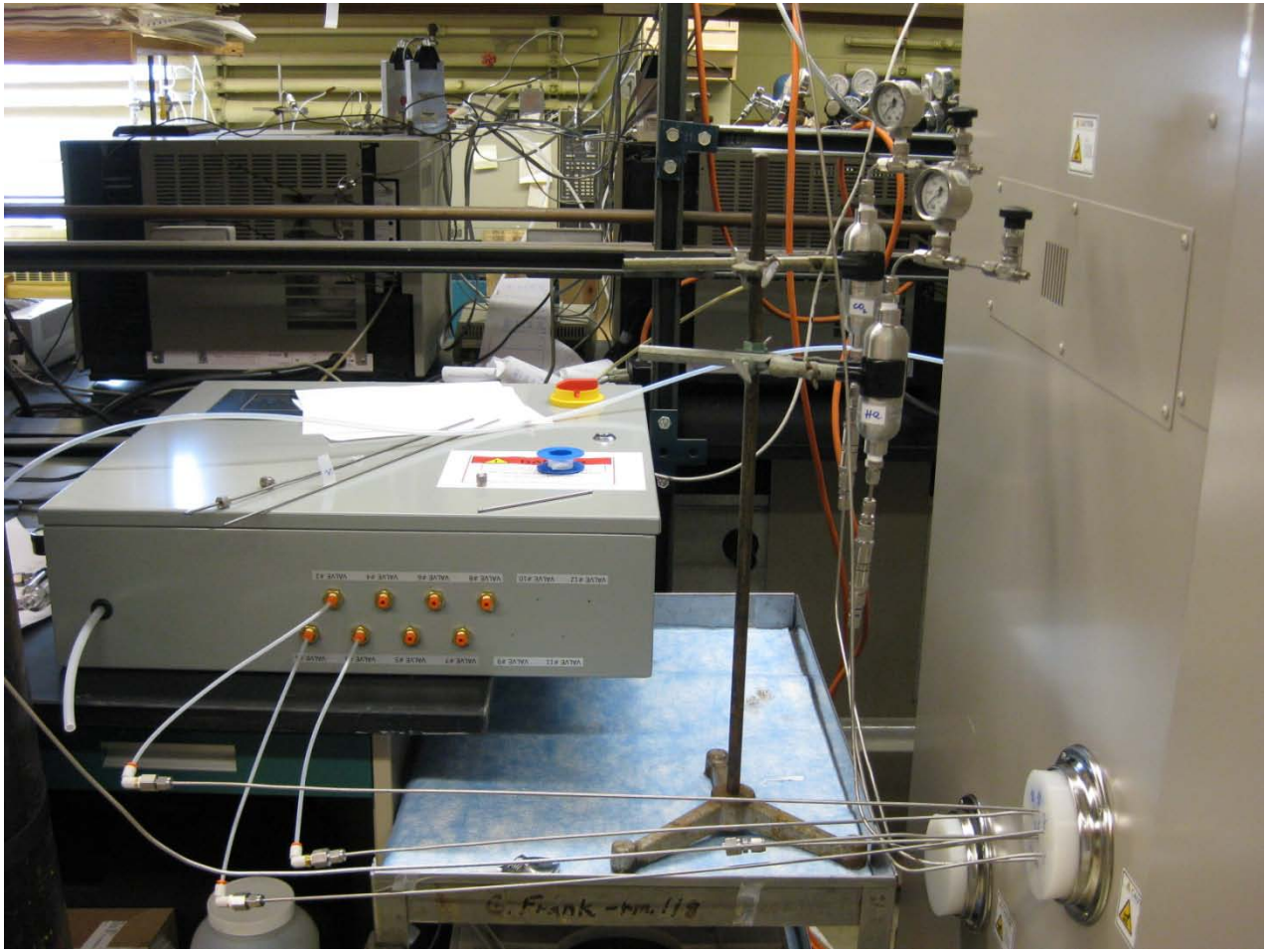


GCs

PneuMagnetic PLC Control Box



PneuMagnetic PLC Control Box with Connections to the Valves inside the Oven



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Project Structure

- Project Structure may be described through the List of Tasks describing in detail the following steps
- Design the device and PSAB process after selecting absorbents and the dimensions of the membrane units
- Build the setup
- Perform separation runs
- Analyze the data and focus on conditions showing the desired performance
- Develop a mathematical model for the process
- Determine the solubility and diffusivity of solutes in the absorbent liquids
- Compare model results with experimental data
- Determine absorbent deterioration with time

Tasks to be Performed: Phase II

- Task 3.0 Project Management and Planning (10/1/10 – 9/30/11)
- Subtask 3.1 Provide quarterly reports at the end of every quarter as well as a Topical Report at the end of year 2 (10/1/10 – 9/30/11)
- Task 4.0 Experimental Program and Technical Activities for Year 2 (10/1/10 – 9/30/11)
- Subtask 4.1 Study the performance of PSAB devices and the PSAB process (10/1/10 – 9/30/11)
- Subtask 4.2 Develop experimental setups to measure solubility and diffusion coefficients of CO_2 and He in selected absorbent liquids (10/1/10 – 9/30/11)
- Subtask 4.3 Initiate development of a mathematical model of the PSAB device and process (10/1/10 – 9/30/11)

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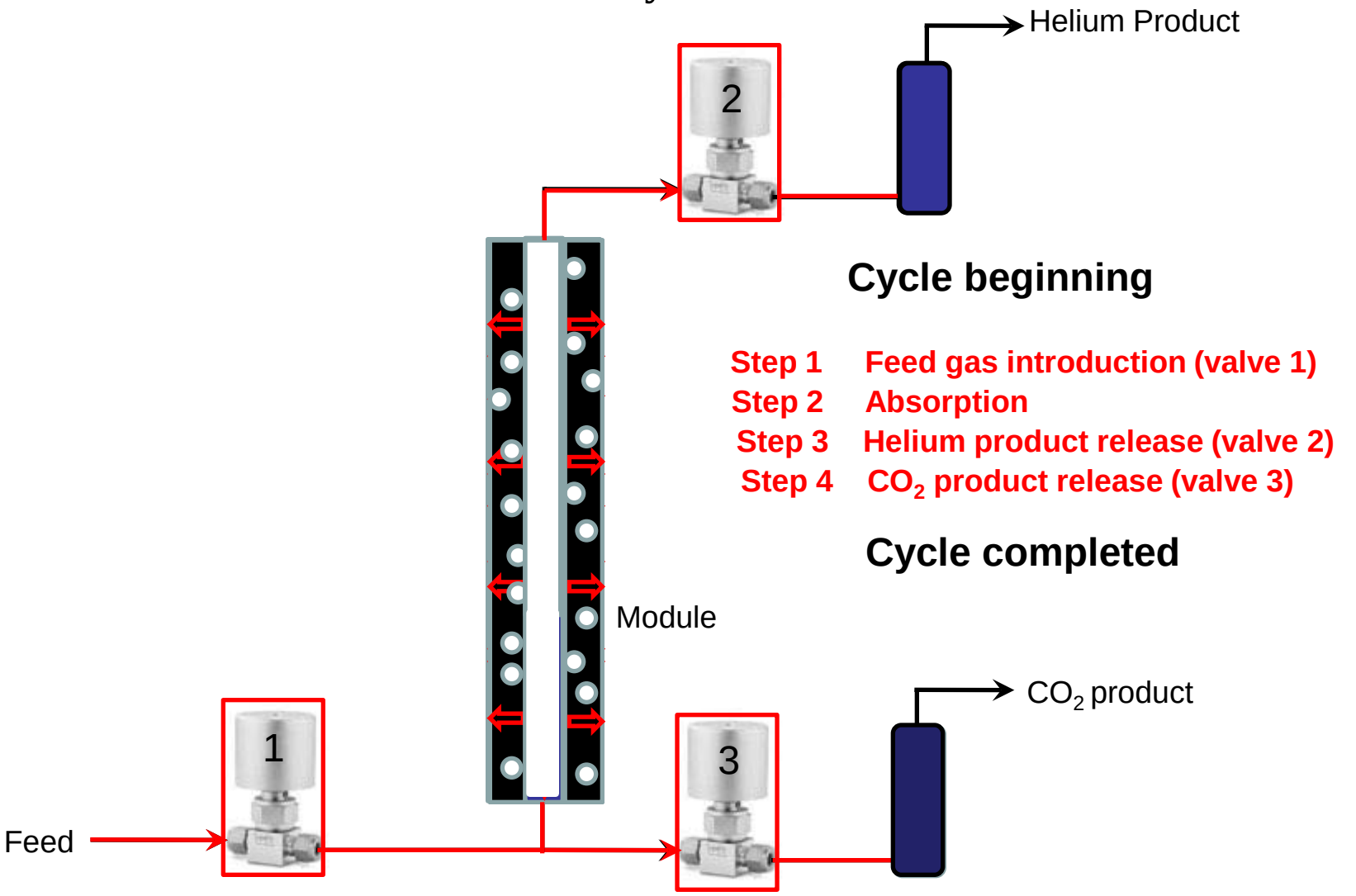
Liquid Breakthrough Pressure Test Results for Membrane Modules Recently Obtained (Phase II)

	Water	[Bmim][DCA]	[Emim][Tf2N]	PEG 400	20% Dendrimer + DCA
Ceramic #7	210 psi	No leakage up to 300 psi	N/A	300 psi	220 psi
Ceramic #8	No leakage up to 300 psi	No leakage up to 300 psi	180 psi	No leakage up to 300 psi	N/A
PEEK #20 Epoxy	No leakage up to 200 psi	40 psi	N/A	140 psi	N/A
PEEK #21 Epoxy	No leakage up to 200 psi	No leakage up to 140 psi	N/A	180 psi	N/A
2” PEEK (2PG295)	No leakage up to 200 psi	No leakage up to 200 psi	No leakage up to 200 psi	No leakage up to 200 psi	N/A
Teflon* (S/N: 1004)	No leakage up to 100 psi	100 psi	N/A	80 psi	100 psi
Teflon* (S/N: 1005)	140 psi	40 psi	N/A	80 psi	40 psi
Teflon* (S/N: 1006)	No leakage up to 140 psi	60 psi	N/A	80 psi	60 psi

Room temperature, dry air sweep, liquid pressurized with nitrogen; *Epoxy-- O-ring seal

Larger Module containing PEEK Hollow Fibers in the Setup

Process of pressure swing absorption for separating CO_2 from shifted syngas: 3-Valve system



High Pressure High Temperature PSAB Test Results of Ceramic Membrane Module with a Single Tubule (N-Valve System)

Feed gas pressure psi	Liquid pressure psi	Cycle time/s & Pressure drop/psi	CO_2 content of Helium product	CO_2 content of CO_2 product
250 (25°C)	260	5; 30; 240; 235;	32.9~33.0%	43.1~44.2%
250 (25°C)	260	5; 30; 240; 235;	31.6~32.0%	43.1~44.2%
250 (25°C)	260	5; 30; 240; 235;	32.2~32.5%	43.1~44.2%
260 (100°C)	280	5; 30; 255; 252;	33.5~34.0%	44.9~45.5%
260 (100°C)	280	5; 30; 255; 252;	33.5~33.6%	44.9~45.5%
260 (120°C)	280	5; 30; 255; 252;	33.7~33.8%	44.7~44.9%

Feed gas composition: 40.67±2 % CO_2, Helium balance. Liquid used for CO_2 absorption: pure [Bmim][DCA]. For all tests dry feed gas was introduced to the tube side of module.

One ceramic membrane module (#8) was used. (One 1/8 inch Teflon rod was inserted into the ceramic tube to reduce the dead volume).

High Pressure PSAB Runs with Longer PEEK Membrane Module (N-Valve System) (~25°C and 100°C)

Feed gas pressure, psi	Liquid pressure, psi	Cycle time/s & Pressure drop/psi	CO_2 content of Helium product	CO_2 content of CO_2 product
100 (25°C)	120	2; 30; 35; 34;	14.1%	45.7~52.6%
150 (25°C)	160	10; 30; 145; 140;	14.6~15.0%	83.0%
200 (25°C)	220	10; 30; 200; 195;	14.8~15.5%	85.3%
250 (25°C)	270	10; 30 250; 244;	16.7%	63.6~69.6%
250 (25°C)	270	10; 60; 250; 243;	15.0%	63.6~69.6%
100 (100°C)	120	5; 30; 100; 97;	22.9%	56.8~65.2%
150 (100°C)	160	5; 30; 149; 145;	25.3~25.6%	51.4~61.0%
150 (100°C)	160	5; 30; 149; 145;	28.8%	51.4~61.0%

Feed gas composition: 40.67±2 % CO_2, Helium balance. Liquid used for CO_2 absorption: pure [Bmim][DCA]. For all tests dry feed gas was introduced to the tube side of module.

One new longer PEEK membrane module was used.

A Few General Conclusions

- The N-valve cycle performs much better than the 3-valve cycle especially regarding the quality of the CO_2 product
- Higher membrane surface area per unit device (gas) volume leads to better separation performance
- Two hollow fiber membrane modules in series deliver higher purity in both product streams compared to one
- Minor difference in performance between humidified feed gas and dry feed gas for pure [bmim][DCA] (at this time!)
- Increase in temperature reduces the performance a bit as we go up to 100^0C
- Hydrophobized PEEK membrane modules yield best results

PSAB performance comparison between 3-valve and N-valve systems using a PEEK membrane module

Feed gas pressure, psi	Liquid pressure, psi	System	Cycle time/s & Pressure drop/psi	CO_2 content of Helium product	CO_2 content of CO_2 product
100	120	N-valve	97.0; 95.0	8.31%	70.10%
100	120	3-valve	5; 30; 1; 30 97.0; 95.0; 75.0; -28.0inHg	8.00%	38.40%
100	120	3-valve	5; 30; 30; 30 97.0; 95.0; 0; -28.0inHg	30.90%	76.95%
120	130	N-valve	117.0; 115.0	7.16%	67.20%
120	130	3-valve	5; 30; 1; 30 117.0; 115.0; 95.0; -28.0inHg	8.18%	39.60%
120	130	3-valve	5; 30; 30; 30 117.0; 115.0; 0; -28.0inHg	33.00%	76.10%

Feed gas composition: 40.67±2 % CO_2, Helium balance. Liquid used for CO_2 absorption: pure [Bmim][DCA]. All tests were carried out at room temperature about 22°C, and dry feed gas was introduced to the tube side of module. Only one PEEK membrane module (No.1 with product number 30-105-21) was used.

Physical dimensional comparison between different membrane modules

Module	OD, cm	ID, cm	Length, cm	Void volume fraction	Pore size, Å	Gas volume, cm^3	Contacting area, cm^2	Surface area / Volume, cm^{-1}
Ceramic	0.57	0.37	44.0	~0.4	50	7.3259	31.5	4.30
Ceramic*						3.8441	31.5	8.19
Teflon	0.108	0.053	44.5	~0.4		0.2218 (1 fiber)	6.0363 (1 fiber)	27.22
PEEK	0.0452	0.0290	34.3	~0.4		0.03559 (1 fiber)	1.9472 (1 fiber)	54.71

Comments:

For a given ratio between the contacting area in one hollow fiber and the corresponding gas volume (this could be directly related with the absorption capability of the module), and assuming all membrane modules have the same void volume fraction of about 0.4, if the separation ability of PEEK module is 100, then that for Teflon module will be 49.8, ceramic module with dead volume reduced will be 15.0 and without dead volume reduced will only be 7.86.

* A Teflon rod was inserted into the tube side of ceramic membrane module to reduce the dead volume. The diameter of Teflon tube is 1/8 inch and about 70% volume in ceramic tube side was reduced.

PSAB performance comparison between different membrane modules

Feed gas composition: 40.67±2 % CO_2, Helium balance. Liquid used for CO_2 absorption: 20wt% Dendrimer in water. For all test, dry feed gas was introduced to the tube side of module. All tests were carried out at room temperature about 24°C.

2 PEEK MODULES IN SERIES

Feed gas pressure, psi	Liquid pressure, psi	CO_2 content of Helium product	CO_2 content of CO_2 product
60	80	5.1%	49.5%
60	80	11.4%	72.0%
80	100	5.1%	57.0%
80	100	14.3%	74.4%
100	110	4.8%	57.0%
100	110	14.4%	74.1%
120	125	5.04%	43.3%
120	125	26.8%	78.0%

Feed gas composition: 40.67±2 % CO_2, Helium balance. Liquid used for CO_2 absorption: pure [Bmim][DCA]. All tests were carried out at room temperature about 22°C, and dry feed gas was introduced to the tube side of module.

1 PEEK MODULE

Feed gas pressure, psi	Liquid pressure, psi	CO_2 content of Helium product	CO_2 content of CO_2 product
60	80	6.57%	63.20%
80	100	6.81%	67.20%
100	110	8.31%	70.10%
120	130	7.16%	67.20%

Feed gas composition: 40.67±2 % CO_2, Helium balance. For all test, dry feed gas was introduced to the tube side of module. Liquid used for CO_2 absorption: 20wt% Dendrimer in water. All tests were carried out at room temperature about 24°C.

1 - TEFLON MODULE

Feed gas, pressure psi	Liquid pressure, psi	CO_2 content of Helium product	CO_2 content of CO_2 product
20	30	20.0%	39.0%
30	40	21.0%	42.0%
50	60	24.0%	43.8%
50	60	29.4%	46.5%
50	60	30.0%	48.0%

Feed gas composition: 40.67±2 % CO_2, Helium balance. Liquid used for CO_2 absorption: pure [Bmim][DCA]. All tests were carried out at room temperature about 24°C, and dry feed gas was introduced to the tube side of module. A Teflon rod was inserted into the tube side of ceramic membrane module to reduce the dead volume. The diameter of Teflon tube is 1/8 inch and about 70% volume in ceramic tube side was reduced.

1 - CERAMIC MODULE

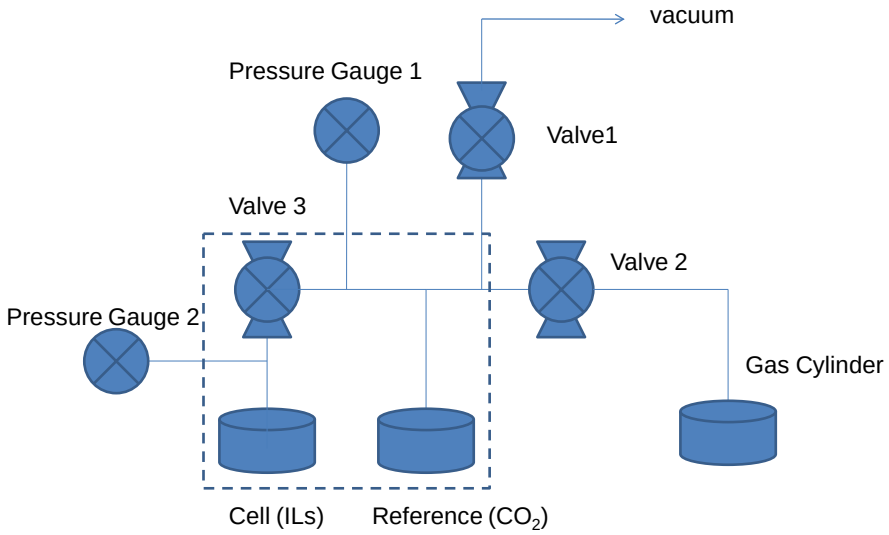
Feed gas, pressure psi	Liquid pressure, psi	CO_2 content of Helium product	CO_2 content of CO_2 product
120	140	32.06%	44.88%
160	180	31.47%	43.20%
180	200	31.47%	41.88%
210	230	31.50%	45.35%

High Temperature Test Results of One PEEK Membrane Module

Test temperature °C	CO_2 content of Helium product	CO_2 content of CO_2 product
24	11.6%	40.5%
60	10.7%	39.1%
70	11.3%	39.6%
80	10.7%	40.2%
90	15.8%	42.0%
100	22.8%	45.0%

Feed gas composition: 40.67±2 % CO_2, Helium balance. Liquid used for CO_2 absorption: 20wt% Dendrimer in PEG-400. For all test, dry feed gas was introduced to the tube side of module. N-valve system was used. One PEEK membrane module was used (30-116-1). All tests were carried out with feed gas pressure at 15psi and liquid pressure at 18psi.

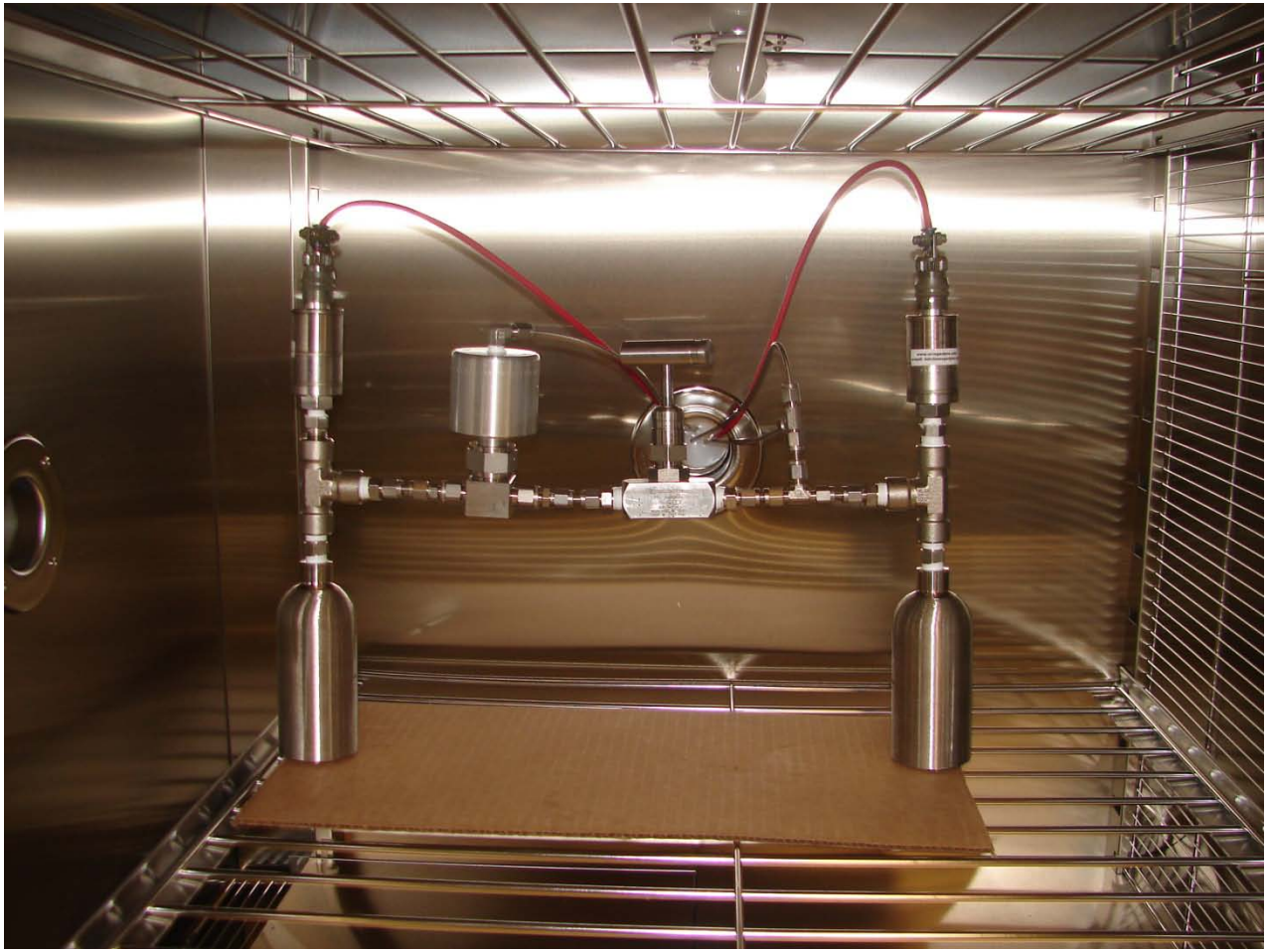
Solubility Measurement Schematic



The solubility measurement system contains a cell volume, a reference volume, an oven, and gas cylinders. The procedure for measuring solubility of a desired gas is described below:

- Fill the cell volume (V_{cell}) with known volumes of ILs (V_{IL})
- The system was vacuumed for at least 12 hrs with all valves open
- Close valves 1 and 3
- Load carbon dioxide gas (or desired gas) into the reference volume (V_{ref}) to a desired pressure.
- Close valve 2
- Allow the temperature of the gas to reach desired temperature in reference volume.
- Open valve 3 to allow gas to contact ILs
- Allow pressure to reach equilibrium (pressure no long changed)
- Final pressure difference was used to calculate the number of moles of gas absorbed by ILs

Solubility Measurement Setup



Model Equations Considering Pressure Drop in Fiber Lumen

- When gas pressure in the fiber lumen is not negligible, the governing balance equations and boundary conditions for any species j (N_2, CO_2) in the gas and liquid phases are shown on the next slide:

- μ_g is the gas mixture viscosity
- D_{jg}, D_{jl}: Diffusion coefficient of species j in gas and liquid phase
- K_{jg}: overall mass transfer coefficient of species j in gas phase
- d_i, d_0: inner and outer diameter of the fiber
- H_j: Henry law constant of species j
- r_e: Happel's radius

Model Equations Considering Pressure Drop in Fiber Lumen (Cont'd)

Gas Phase: $\frac{\partial C_{ig}}{\partial t} = D_{jg}\frac{\partial^2 C_{jg}}{\partial z^2} - \frac{\partial}{\partial z}(v_g C_{jg}) - \frac{4K_{jg}d_o}{d_i^2}(C_{ig} - C_{ig}^i)$

where $v_g = -\frac{RTd_i^2}{32\mu_g}\sum_{j=1}^{n}\frac{\partial C_{ig}}{\partial z}$

$C_{ig}^i = \frac{C_{jl@r=r_o}}{RTH_j}$

Initial condition: at t=0, $C_{jg} = 0\ (0 \le z \le L)$

Boundary conditions:

$v_g C_{jg}\big|_u = v_g C_{jg}\big|_{z=0} - D_{jg}\frac{\partial C_{jg}}{\partial z}\Big|_{z=0}$

$D_{jg}\frac{\partial C_{jg}}{\partial z}\Big|_{z=1} = 0$

Liquid Phase: $\frac{\partial C_{jl}}{\partial t} = D_{jl}\left(\frac{\partial^2 C_{jl}}{\partial r^2} + \frac{1}{r}\frac{\partial C_{jl}}{\partial r}\right)$

Initial condition: at t=0, $c_{jl} = 0\ (0 \le z \le L \text{ and } r_0 \le r \le r_e)$

Boundary conditions:

$-D_{jl}\frac{\partial C_{jl}}{\partial r}\Big|_{r=r0} = K_{jg}\left(C_{jg} - \frac{C_{jl@\ r=r_o}}{RTH_j}\right)$

$\frac{\partial C_{jl}}{\partial r}\Big|_{r=re} = 0$

Tasks to be Performed: Phase III

- Task 5.0 Project Management and Planning (10/1/11 – 9/30/12)
- Subtask 5.1 Provide quarterly reports at the end of every quarter as well as the final Project Report at the end of year 3 (10/1/11 – 12/31/12)
- Task 6.0 Experimental Program and Technical Activities for Year 3 (10/1/11-9/30/12)
- Subtask 6.1 Determine the solubility and diffusivity of CO_2 and He in selected absorbents (10/1/11-6/30/12)
- Subtask 6.2 Compare mathematical model simulation results with experimental data from PSAB process (10/1/11-9/30/12)
- Subtask 6.3 Numerically explore scale up of the process to facilitate evaluation of the process (3/1/12-9/30/12)
- Subtask 6.4 Determine the loss/deterioration of the absorbents, especially amines, over extended periods (10/1/11-9/30/12)

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- Technology Description

(a) Process and Device Concept

(b) Detailed Considerations on Process and Device

- Project Objectives
- Phase I
- Project Structure
- Phase II
- **Project Budget**
- Project Management Plan including Risk Management

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Project Budget

- We have spent already bulk of the money budgeted for Phase II
- Most of the remaining money will be spent by 09-30-11

Project Management Plan

- Project Manager : Prof. Kamalesh K. Sirkar, PI, NJIT
- Post-Doctoral Fellow 1: Dr. Gordana Obuskovic, NJIT (Part time)
- Post-Doctoral Fellow 2: Dr. Jie Xingming, NJIT (Full time)
- Graduate Students: Mr. John Chau, NJIT, fully supported
- Consultant : Dr. Ashok Damle, Techverse Inc., Cary, NC

The Project Manager will interact with the following companies fabricating microporous hollow fiber membranes/tubules:

1. Applied Membrane Technology, Minnetonka, MN (AMT): Stephen Conover, Thomas McEvoy, Dr. Ashok Sharma on porous hollow fiber membranes of Teflon
2. Media & Process Technology, Pittsburgh, PA (M&P): Dr. Paul K.T. Liu, Richard Ciora on coating of the surfaces of ceramic tubules of alumina
3. Porogen Inc., Woburn, MA: Dr. Ben Bikson on porous hydrophobized PEEK hollow fiber modules

Risk Management

- To prevent leakage of absorbent through microporous PTFE hollow fibers having a plasma polymerized microporous fluorosilicone coating, a finer starting pore size and a provision for leakage collection at the end of tube side

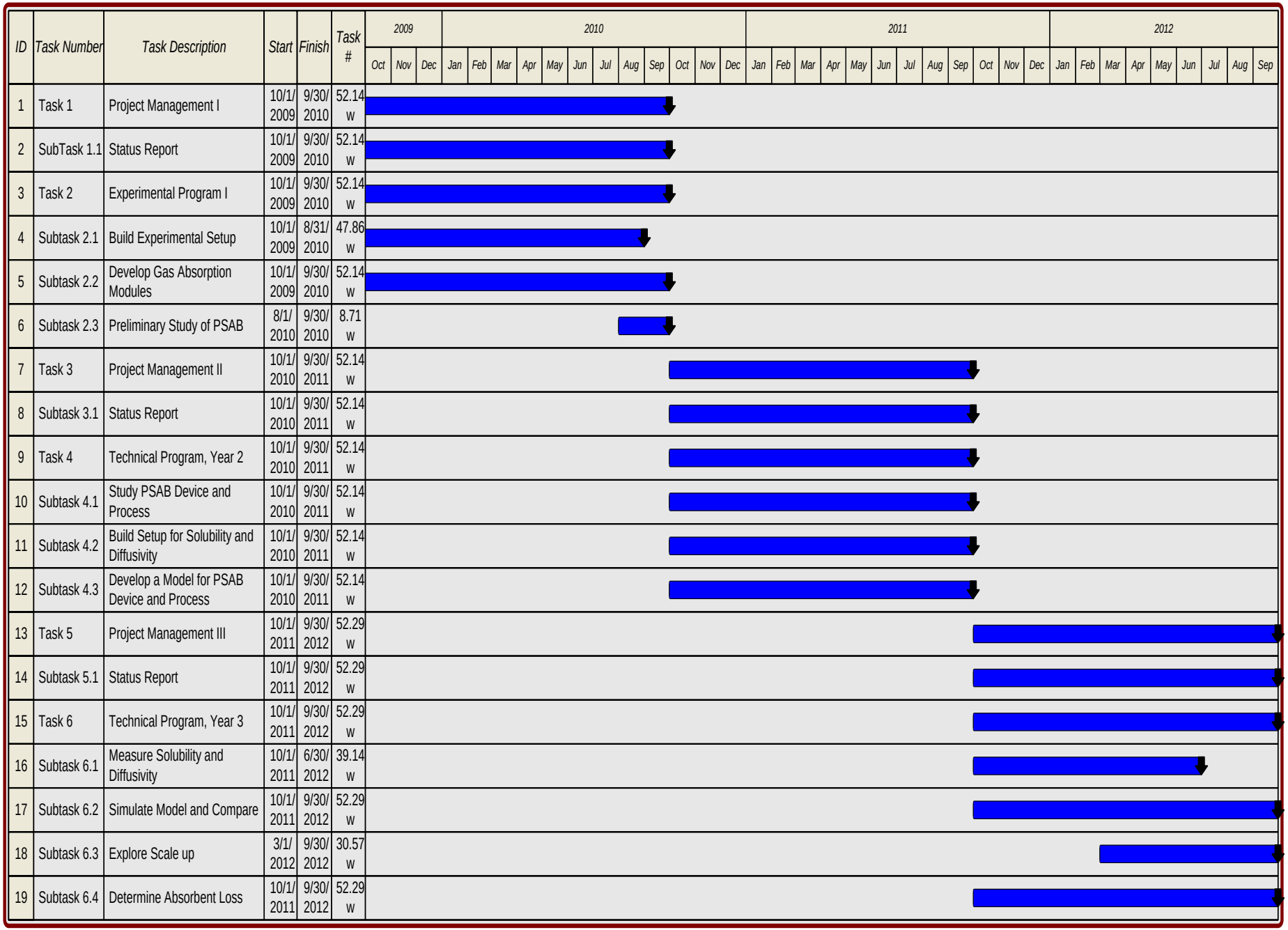
- Capability of the hydrophobic coatings on ceramic tubules to hydrophobize them sufficiently (avoid defects) to eliminate leakage of absorbent into the tube side: make provision for leakage collection at the end of tube-side and a finer starting pore size

- Effect of module diameter and length on He purification ability: smallest possible tubule diameter; increase module length by connecting them in series (oven dimension limitations)

- Achieve a steady state in the cyclic process by preventing a drift in the composition and amount of two purified product streams obtained: balance cycle between absorption and regeneration; fine tune the system

Project Timeline

ID	Task Number	Task Description	Start	Finish	Task #
1	Task 1	Project Management I	10/1/2009	9/30/2010	52.14 w
2	SubTask 1.1	Status Report	10/1/2009	9/30/2010	52.14 w
3	Task 2	Experimental Program I	10/1/2009	9/30/2010	52.14 w
4	Subtask 2.1	Build Experimental Setup	10/1/2009	8/31/2010	47.86 w
5	Subtask 2.2	Develop Gas Absorption Modules	10/1/2009	9/30/2010	52.14 w
6	Subtask 2.3	Preliminary Study of PSAB	8/1/2010	9/30/2010	8.71 w
7	Task 3	Project Management II	10/1/2010	9/30/2011	52.14 w
8	Subtask 3.1	Status Report	10/1/2010	9/30/2011	52.14 w
9	Task 4	Technical Program, Year 2	10/1/2010	9/30/2011	52.14 w
10	Subtask 4.1	Study PSAB Device and Process	10/1/2010	9/30/2011	52.14 w
11	Subtask 4.2	Build Setup for Solubility and Diffusivity	10/1/2010	9/30/2011	52.14 w
12	Subtask 4.3	Develop a Model for PSAB Device and Process	10/1/2010	9/30/2011	52.14 w
13	Task 5	Project Management III	10/1/2011	9/30/2012	52.29 w
14	Subtask 5.1	Status Report	10/1/2011	9/30/2012	52.29 w
15	Task 6	Technical Program, Year 3	10/1/2011	9/30/2012	52.29 w
16	Subtask 6.1	Measure Solubility and Diffusivity	10/1/2011	6/30/2012	39.14 w
17	Subtask 6.2	Simulate Model and Compare	10/1/2011	9/30/2012	52.29 w
18	Subtask 6.3	Explore Scale up	3/1/2012	9/30/2012	30.57 w
19	Subtask 6.4	Determine Absorbent Loss	10/1/2011	9/30/2012	52.29 w



Milestone Log

PHASE I

- Milestone 1: Novel absorption module fabrication successfully completed (9/30/10)
- Milestone 2: PSAB experimental setup completed (8/31/10)
- Milestone 3: PSAB device appears to function well (9/30/10)

PHASE II

- Milestone 4: PSAB device achieving high purification of He and CO_2 streams (8/31/11)
- Milestone 5: Experimental setups for measuring solubility and diffusivity completed (9/30/11)

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Milestone Log

PHASE III

- Milestone 6: Mathematical Model of PSAB developed (4/30/12)
- Milestone 7: Solubilities and diffusivities of CO_2 and He measured (4/30/12)
- Milestone 8: PSAB process simulated successfully vis-à-vis experimental performance (7/31/12)
- Milestone 9: Absorbent liquid characterized and degradation determined (9/31/12)
- Milestone 10: Scaleup and economic evaluation conducted (9/31/12)

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Closing Comments

- Special thanks to DOE Program Officers for the project, Norman Popkie, Steven R. Markovitch
- We thank you for your attention
- I would be happy to respond to your questions