# Feasibility Study of Miniature Oxygen Concentrator via Pressure Swing Adsorption

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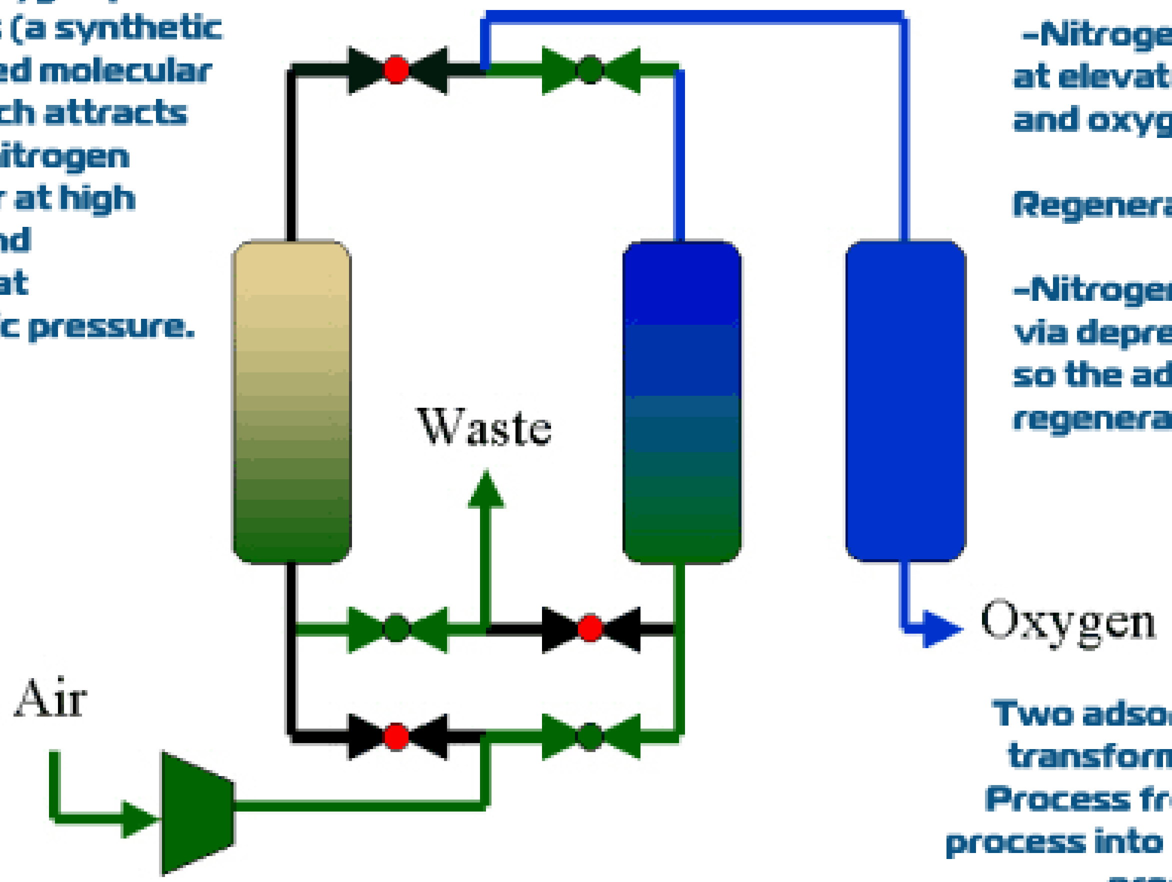
# Oxygen Generation Process via Pressure Swing Adsorption

The PSA oxygen process uses adsorbents (a synthetic zeolite called molecular sieve), which attracts (adsorbs) nitrogen from the air at high pressure and releases it at atmospheric pressure.




**Adsorption Step**

-Nitrogen is adsorbed at elevated pressure and oxygen is produced

**Regeneration Step**

-Nitrogen is desorbed via depressurization so the adsorbent is regenerated

Two adsorbent beds transform the PSA Process from a batch process into a continuous process

Oxygen Generation Process

# Why smaller PSA Oxygen Concentrator?

- **$N_2$ adsorbed onto and desorbed from zeolite micro pores easier?**
  (less tortuous gas travel path due to small diameter bed?)
- **Less purging gas required?**
  (more efficient cleaning in small diameter bed?)
- **Faster operation?**
  (shorter time for pressurization in small volume?)
- **More efficient operation?**
  (less dead volume?)
- **Less hazardous?**
  (shorter time for pressurization and less oxygen storage?)
- **More precise system to be controlled?**
  (less dead volume involved?)
- **Less product loss during depressurization?**
  (less product holdup in small bed?)
- **Less energy consumption?**

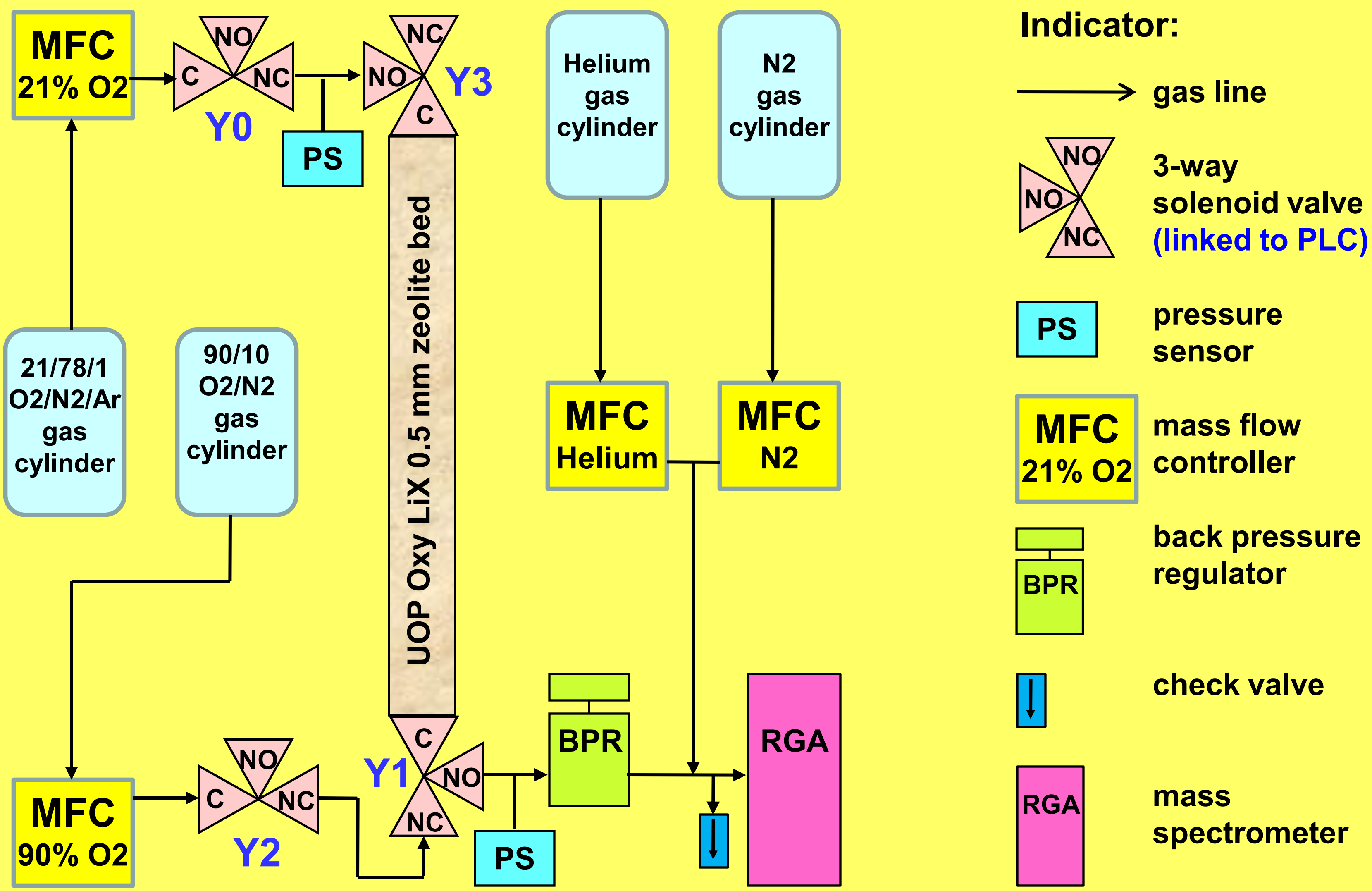
# Application Areas

- Portable respiratory device
- Miniature oxygen provider in electronic device

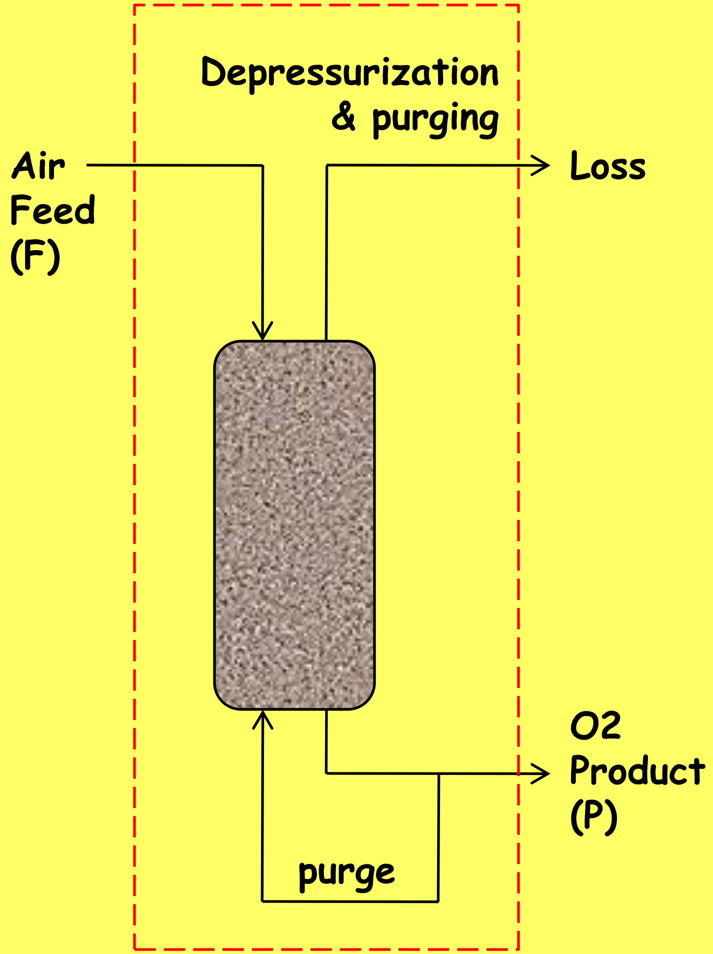
# Objectives

1. To characterize the operating conditions of small PSA systems
2. To compare performances of PSA systems of different sizes
3. To infer feasibility from the performances of current design pieces

# Experimental Setup



# Single Bed Process Cycle




**Simplified Skarstrom Cycle** — **Energize PLC**

1. Counter-current depressurization — Y3
2. Counter-current purging using product — Y1, Y2, Y3
3. Co-current pressurization using air — Y0
4. Co-current adsorption & production — Y0

**Variables:**

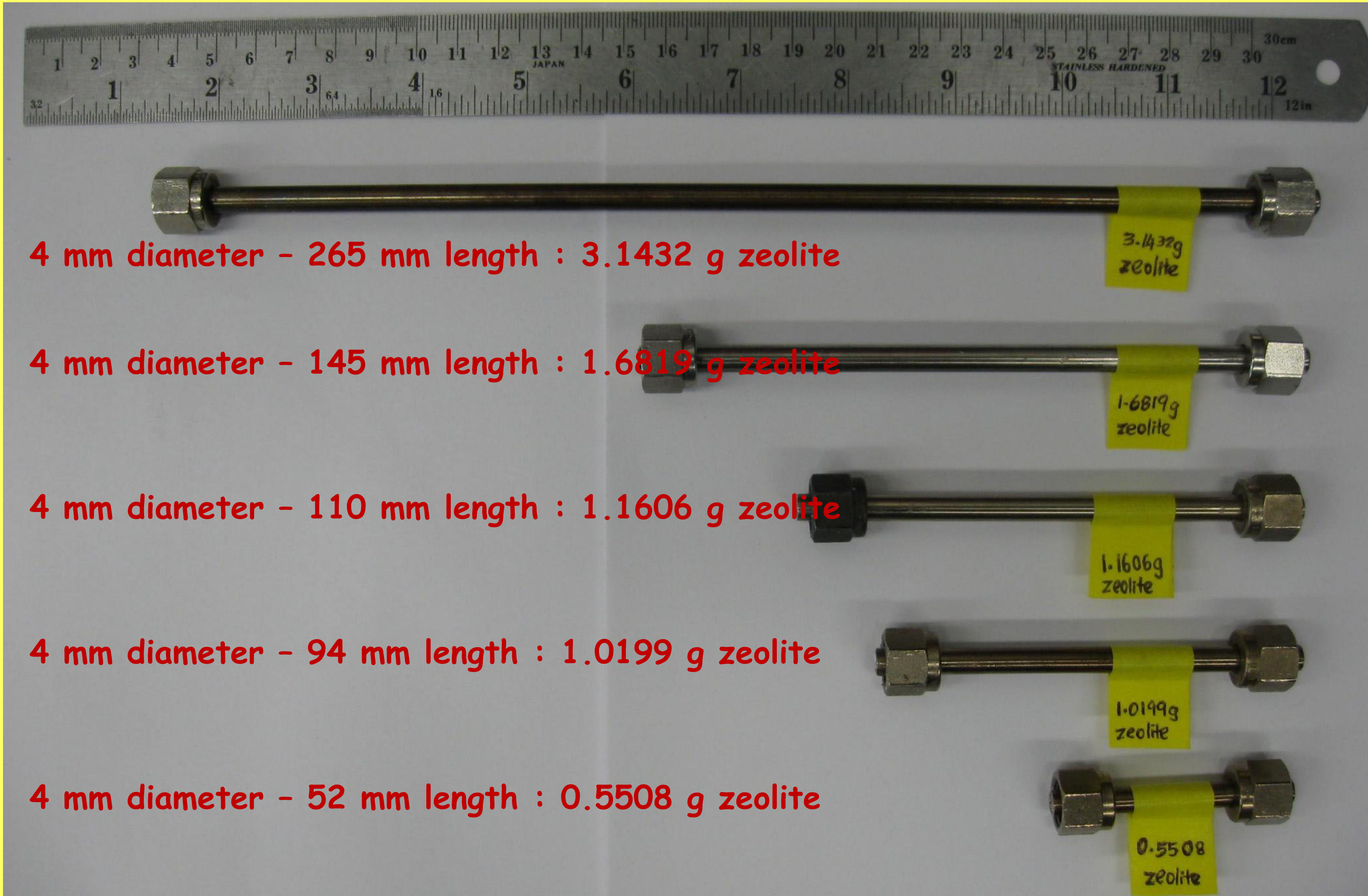
- Depressurization time
- Purging time, flow rate
- Pressurization time, flow rate
- Adsorption time, flow rate

**Performance Index:**

O2 Recovery = $y_p(P)/0.21(F)$

Productivity = $y_p(P)$/g zeolite/hr

# Beds of Different Sizes




4 mm diameter – 265 mm length : 3.1432 g zeolite

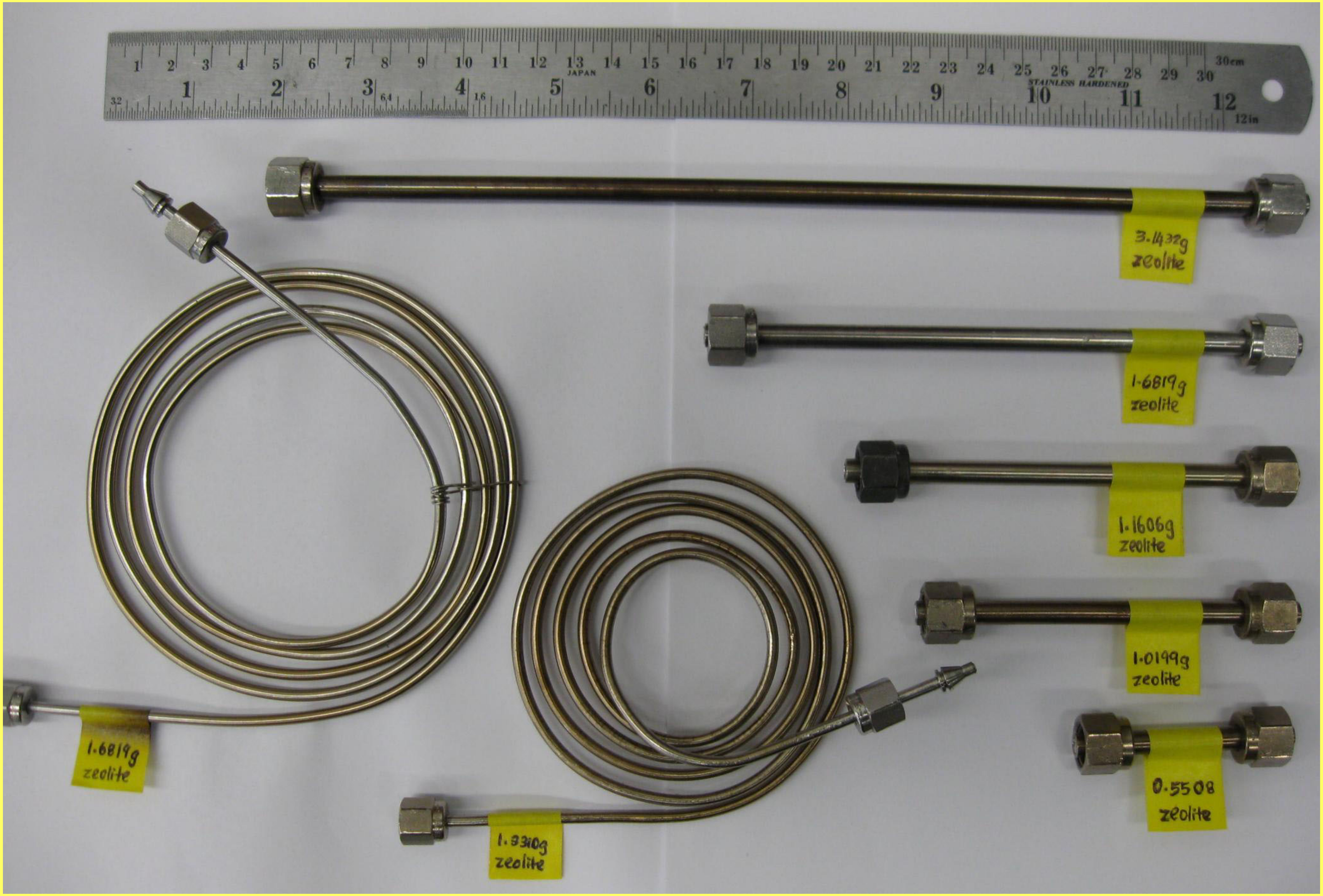
4 mm diameter – 145 mm length : 1.6819 g zeolite

4 mm diameter – 110 mm length : 1.1606 g zeolite

4 mm diameter – 94 mm length : 1.0199 g zeolite

4 mm diameter – 52 mm length : 0.5508 g zeolite

# Is PSA possible in long capillary tube?



# Characterization


**System A and System B contain the same amount of zeolite but in different shapes**

**Find suitable operational parameters:**

1. Depressurization time
2. Purge flow rate
3. Feed flow rate

**Compare performances:**

1. Product purity
2. O2 recovery
3. Productivity

# General Methodology for Characterization

## Determine the capacity of the bed

- Purge the bed with product oxygen for long time
- Carry out adsorption step (pressurization and production) for long time
- Observe the breakthrough time of the bed

## Set appropriate step times

- Set pressurization and adsorption time shorter than the breakthrough time
- Set a depressurization time long enough to desorb N2 from zeolite (by observing the blown down gas approaching zero flow from the bed)
- Set a purging time a little longer than it needs to purge clean the bed (by gradually reducing purge time but getting the same performance)

## Determine the adsorption capability of the bed at the highest pressure

- Tune the back pressure regulator to the highest pressure which is sustainable by all upstream equipment
- To reduce cycle time, use the highest flow rates of air feed and purge gas to carry out PSA cycle
- Slowly reduce purging time to increase oxygen recovery and productivity

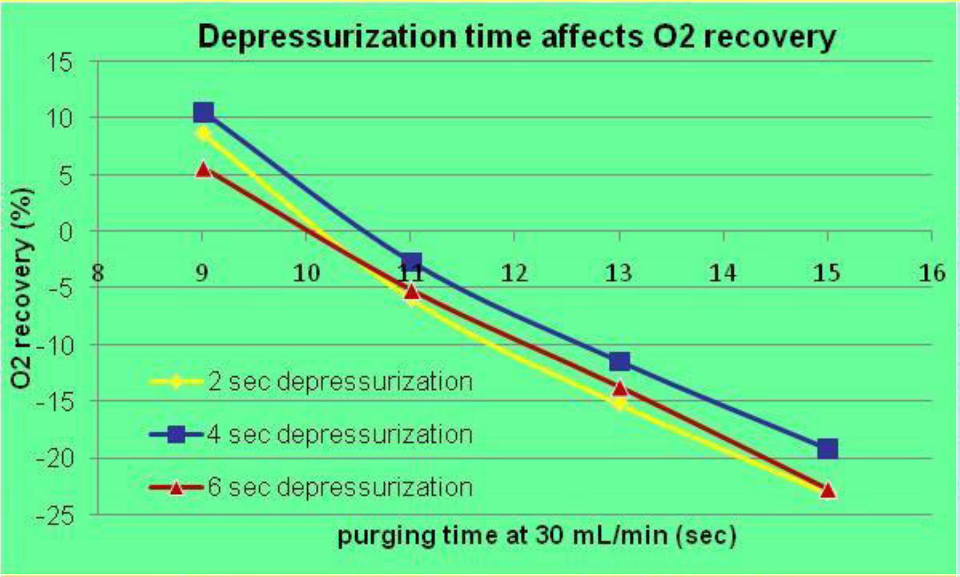
## Optimize cycle time, compression cost and production

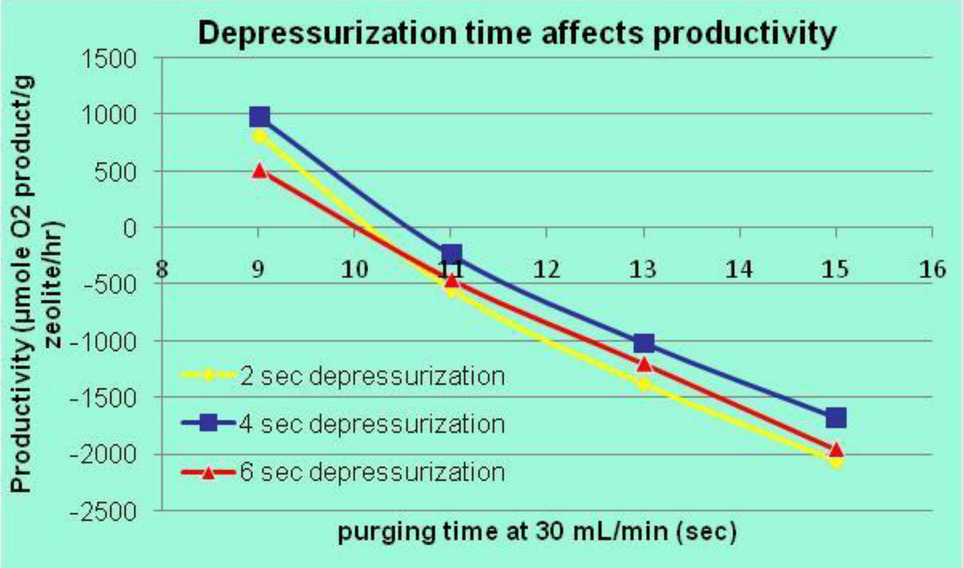
- With the assurance of getting positive adsorption results from the zeolite bed at the highest pressure, now perform optimization
- Carry out PSA cycle at lower adsorption pressure, which shortens the pressurization time and saves compression cost
- Continue to reduce purging time and play with purging flow rate to increase oxygen recovery and productivity

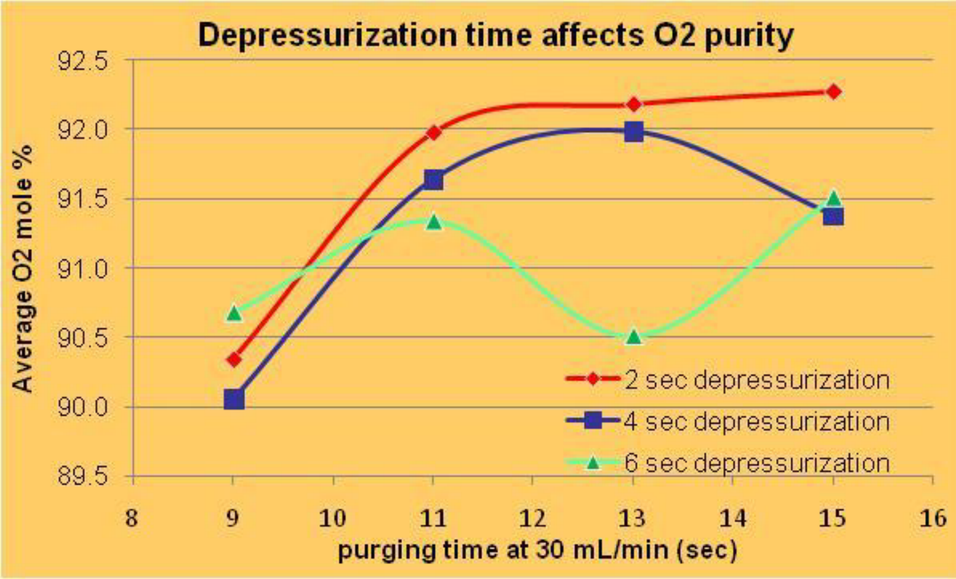
# Overall results of System A (16 – 20 September 2008)

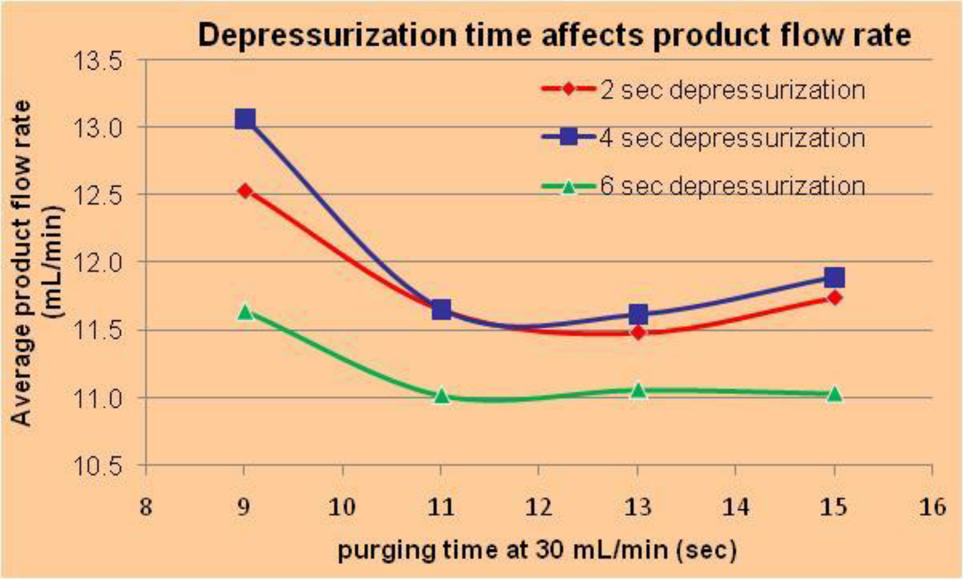
| Depressurization time (sec) | Purging time (sec) | Pressurization and Adsorption time (sec) | Production time (sec) | Maximum | | Average | | O2 recovery (%) | Productivity (µmole O2 product/g zeolite/cycle) | Productivity (µmole O2 product/g zeolite/hr) |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | mL/min | mole % | mL/min | mole % | | | |
| 47- 46.6 psi | 30 mL/min | 30 mL/min | **choosing the appropriate adsorption time** | | | | | | | |
| 4 | 15 | 100 | 24 | 17.4 | 94.6 | 11.1 | 91.5 | -26.02 | -75.11 | -2272.15 |
| 4 | 15 | 105 | 28 | 17.8 | 94.1 | 12.2 | 92.1 | -14.47 | -43.85 | -1273.09 |
| 4 | 15 | 108 | 30 | 20.3 | 93.9 | 13.5 | 92.1 | -5.35 | -16.68 | -472.82 |
| 47- 46.6 psi | 30 mL/min | 30 mL/min | **4 sec depressurization time yields the best results** | | | | | | | |
| 4 | 15 | 102 | 26 | 18.3 | 94.6 | 11.9 | 91.4 | -19.17 | -56.46 | -1679.81 |
| 4 | 13 | 102 | 26 | 18.0 | 94.6 | 11.6 | 92.0 | -11.45 | -33.72 | -1020.18 |
| 4 | 11 | 102 | 26 | 17.9 | 94.2 | 11.7 | 91.6 | -2.65 | -7.81 | -240.46 |
| 4 | 10 | 102 | 26 | 17.8 | 93.8 | 11.8 | 91.5 | 2.01 | 5.92 | 183.72 |
| **4** | **9** | **102** | **26** | **21.1** | **92.3** | **13.1** | **90.1** | **10.61** | **31.24** | **977.88** |
| *4* | *8* | *102* | *exhausted* | | | | | | | |
| 47- 46.6 psi | 30 mL/min | 30 mL/min | **6 sec depressurization time causes too much product loss** | | | | | | | |
| 6 | 15 | 102 | 26 | 17.5 | 94.5 | 11.0 | 91.5 | -22.66 | -66.74 | -1953.31 |
| 6 | 13 | 102 | 26 | 17.9 | 94.6 | 11.1 | 90.5 | -13.65 | -40.21 | -1196.26 |
| 6 | 11 | 102 | 26 | 18.1 | 94.5 | 11.0 | 91.3 | -5.11 | -15.06 | -455.48 |
| 6 | 9 | 102 | 26 | 19.0 | 93.5 | 11.6 | 90.7 | 5.67 | 16.71 | 514.12 |
| *6* | *8* | *102* | *exhausted* | | | | | | | |
| 47- 46.6 psi | 30 mL/min | 30 mL/min | **2 sec depressurization time causes incomplete N2 desorption** | | | | | | | |
| *2* | 15 | *102* | *24* | *17.9* | *94.6* | 11.7 | 92.3 | *-23.06* | *-67.90* | *-2054.04* |
| 2 | 13 | 102 | 24 | 17.7 | 94.7 | 11.5 | 92.2 | -15.17 | -44.66 | -1374.12 |
| 2 | 11 | 102 | 24 | 18.0 | 94.4 | 11.7 | 92.0 | -5.89 | -17.33 | -542.59 |
| 2 | 9 | 102 | 26 | 21.1 | 92.6 | 12.5 | 90.3 | 8.73 | 25.72 | 819.41 |
| *2* | *8* | *102* | *exhausted* | | | | | | | |
| 47- 46.6 psi | **30, 20, 10 mL/min** | 30 mL/min | **comparing the performances at different purging flow rates** | | | | | | | |
| **4** | **9** | **102** | **26** | **21.1** | **92.3** | **13.1** | **90.1** | **10.61** | **31.24** | **977.88** |
| 4 | **13.5** | 102 | 26 | 19.3 | 93.7 | 11.6 | 89.3 | 6.14 | 18.09 | 544.96 |
| 4 | **27** | 102 | 24 | 17.6 | 94.1 | 10.5 | 88.2 | 1.42 | 4.18 | 113.11 |

# System A: Results (I)

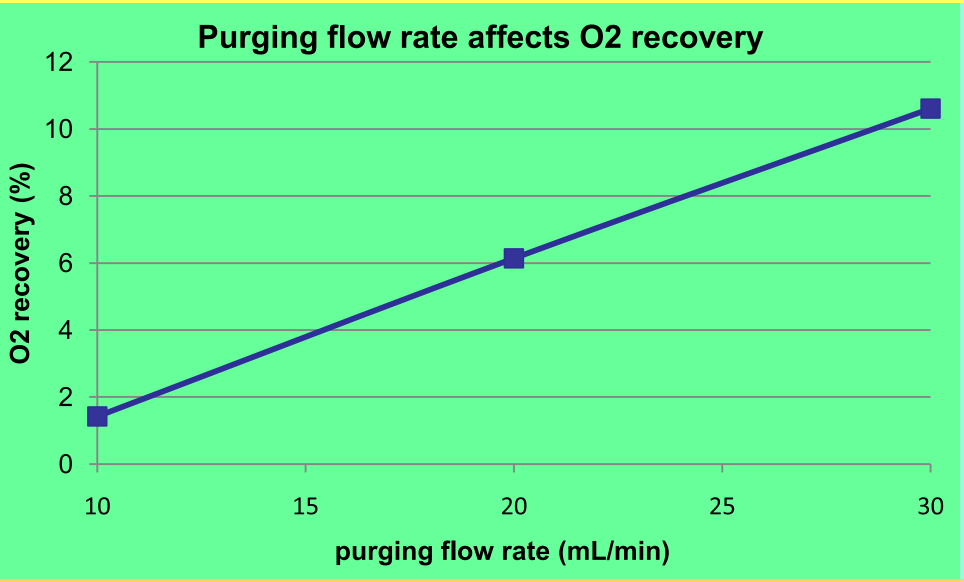


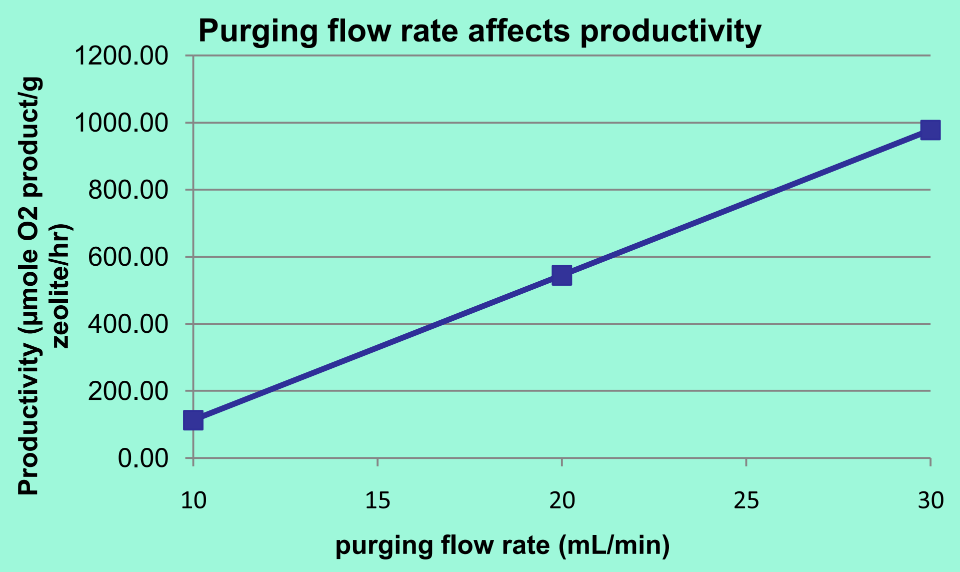



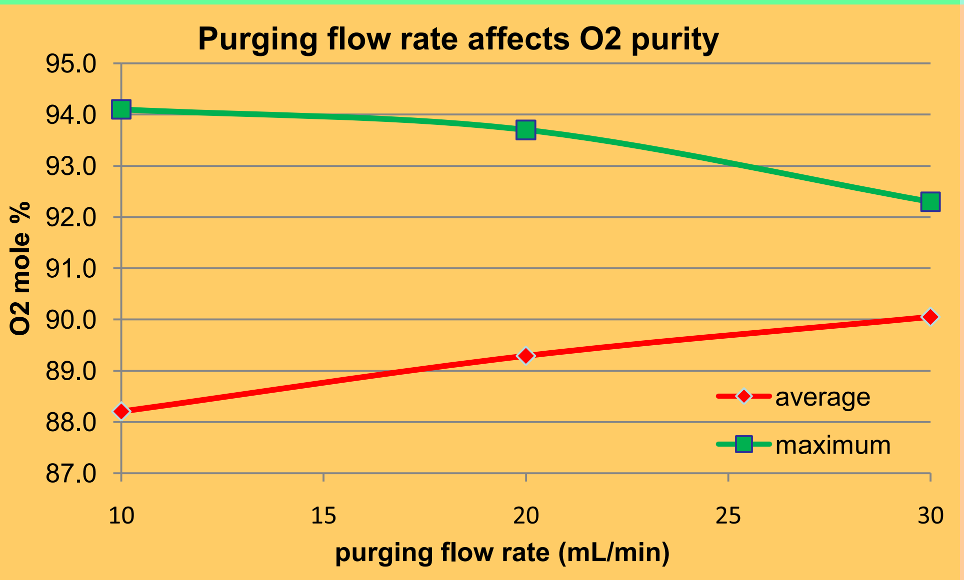



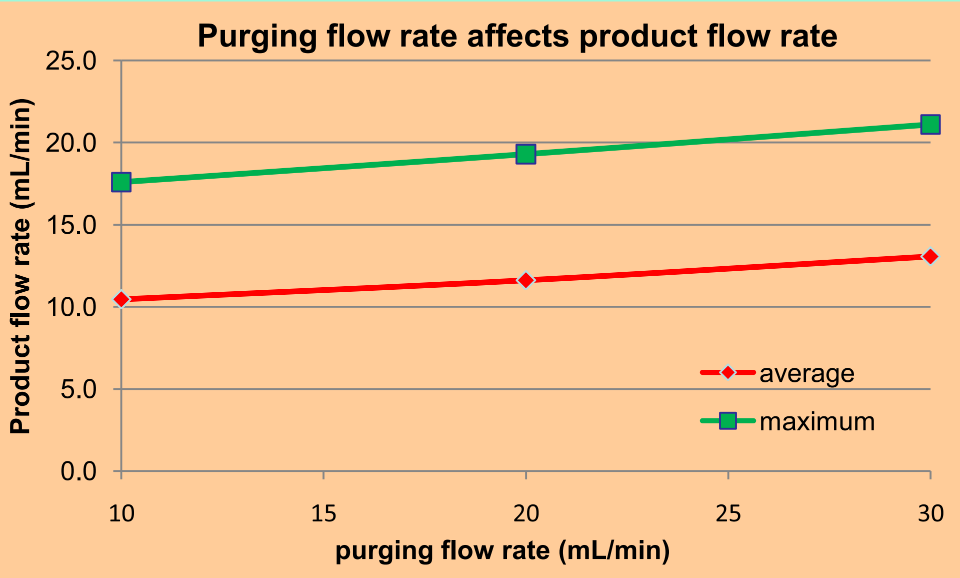



# System A: Results (II)



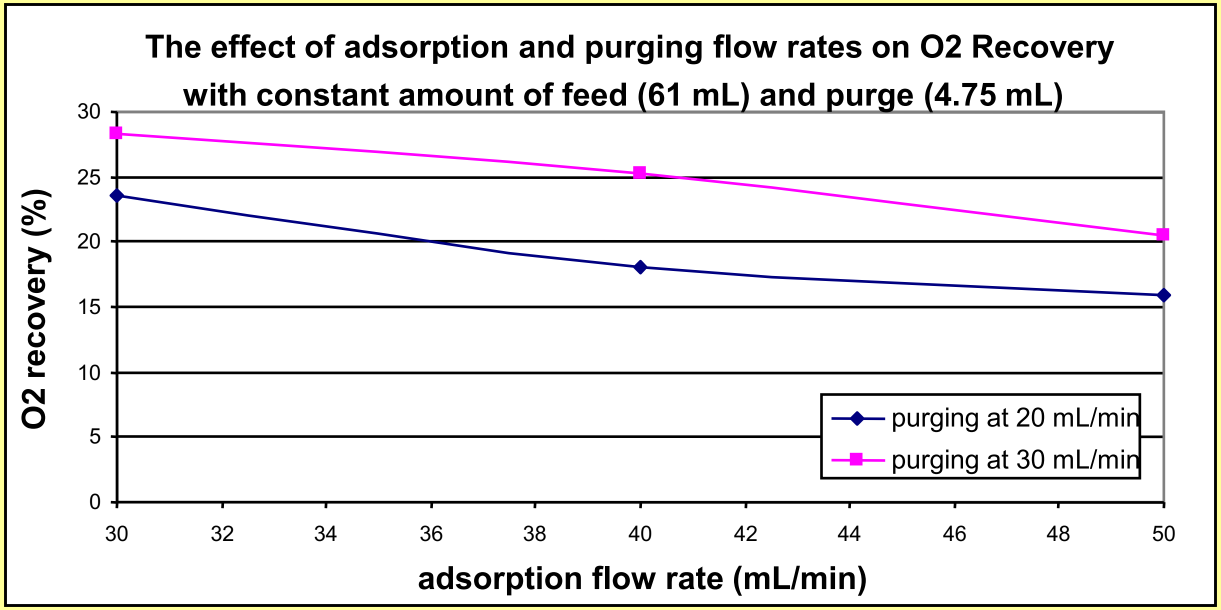



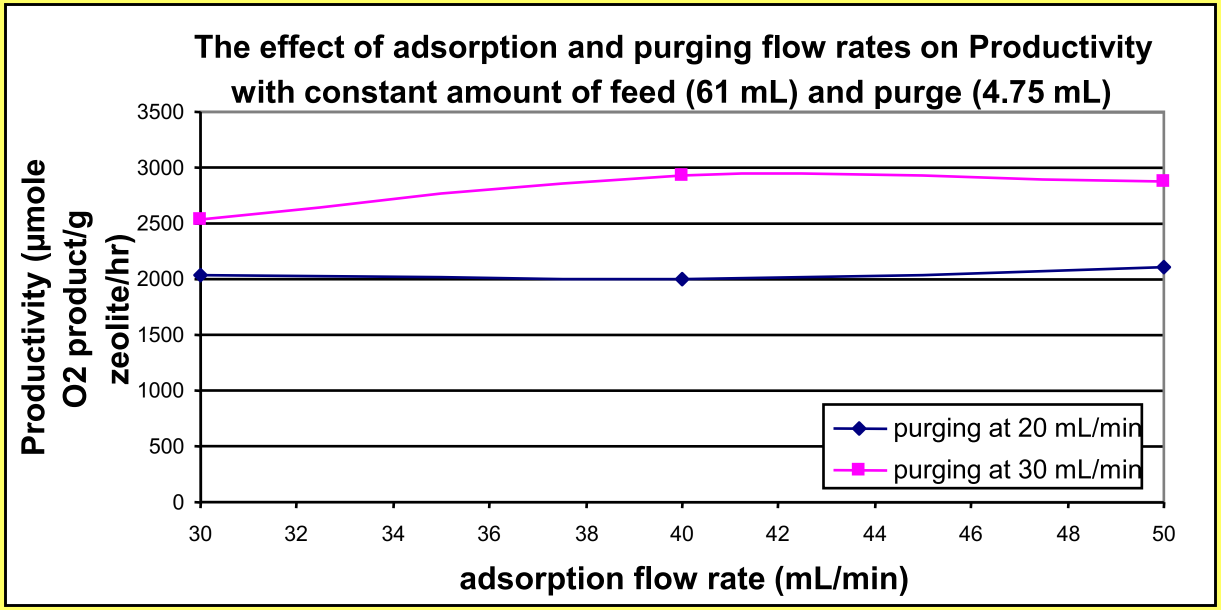



# Overall results of System A (27 - 28 September 2008)

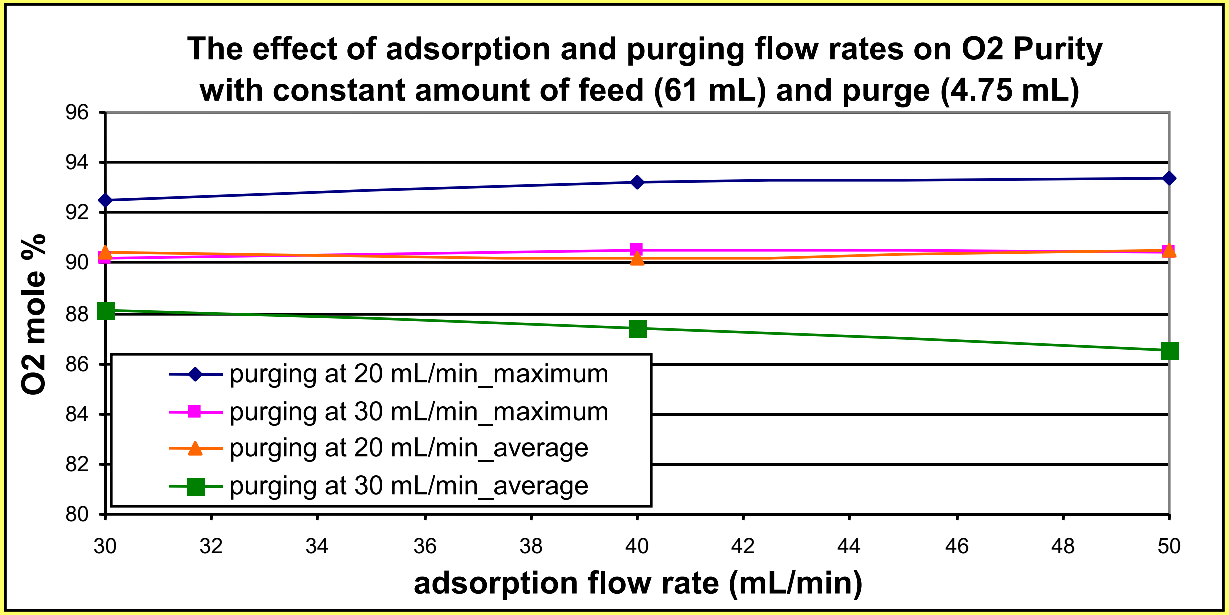
| Depressurization time (sec) | Purging time (sec) | Pressurization and Adsorption time (sec) | Production time (sec) | Maximum | | Average | | O2 recovery (%) | Productivity (µmole O2 product/g zeolite/cycle) | Productivity (µmole O2 product/g zeolite/hr) |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | mL/min | mole % | mL/min | mole % | | | |
| 46.2 - 45.8 psi | 30 mL/min | **30 mL/min** | **Low feed flow rate yields to slow production rate (low productivity/hr), but experience more complete separation (high O2 recovery and productivity/cycle)** | | | | | | | |
| 4 | 13 | 122 | 36 | 15.3 | 94.0 | 10.2 | 90.8 | 2.22 | 7.49 | 194.00 |
| 4 | 11 | 122 | 36 | 15.3 | 93.7 | 10.7 | 91.0 | 11.40 | 38.44 | 1010.14 |
| ***4*** | ***9.5*** | ***122*** | ***38*** | ***21.5*** | ***90.2*** | ***13.1*** | ***88.1*** | ***28.26*** | ***95.26*** | ***2530.88*** |
| **4** | **9** | **122** | **38** | **17.1** | **91.7** | **11.6** | **89.3** | **23.91** | **80.59** | **2149.03** |
| *4* | *8* | *122* | *exhausted* | | | | | | | |
| 46.2 - 45.8 psi | 30 mL/min | **40 mL/min** | **this feed flow rate is not too slow to produce product and is not too fast that causing less efficient separation, but the purity is on the verge of exhaustion** | | | | | | | |
| 4 | 13 | 91.5 | 28 | 19.4 | 94.3 | 13.2 | 91.5 | 3.36 | 11.33 | 375.96 |
| 4 | 11 | 91.5 | 30 | 19.5 | 93.9 | 13.3 | 90.3 | 13.72 | 46.33 | 1565.99 |
| ***4*** | ***9.5*** | ***91.5*** | ***30*** | ***25.8*** | ***90.5*** | ***15.5*** | ***87.4*** | ***25.24*** | ***85.22*** | ***2921.86*** |
| *4* | *9* | *91.5* | *exhausted* | | | | | | | |
| 4 | 13 | 91.5 | 30 | 19 | 94.2 | 12.5 | 91.2 | 3.78 | 12.76 | 423.37 |
| 4 | 11 | 91.5 | 30 | 19.2 | 94 | 13.2 | 91.7 | 13.53 | 45.67 | 1543.77 |
| ***4*** | ***9.5*** | ***91.5*** | ***30*** | ***27.2*** | ***90.1*** | ***15.6*** | ***88.1*** | ***25.28*** | ***85.33*** | ***2925.75*** |
| *4* | *9* | *91.5* | *exhausted* | | | | | | | |
| 46.2 - 45.8 psi | 30 mL/min | **50 mL/min** | **High feed flow rate yields to fast production rate (high productivity/hr), but experience less complete separation (low O2 recovery and productivity/cycle)** | | | | | | | |
| 4 | 13 | 73.2 | 26 | 22.6 | 94.4 | 13.0 | 90.7 | -0.35 | -1.16 | -46.49 |
| 4 | 11 | 73.2 | 26 | 22.9 | 94.2 | 14.0 | 91.1 | 9.71 | 32.76 | 1336.95 |
| **4** | **9.5** | **73.2** | **26** | **25.9** | **92.4** | **15.8** | **89.9** | **20.16** | **67.97** | **2822.16** |
| ***4*** | ***9.5*** | ***73.2*** | ***26*** | ***29.5*** | ***90.4*** | ***16.3*** | ***86.5*** | ***20.57*** | ***69.35*** | ***2879.55*** |
| *4* | *9* | *73.2* | *exhausted* | | | | | | | |
| 46.2 - 45.8 psi | **20 mL/min** | **30,40,50 mL/min** | **Low purging flow rate yields to lower O2 recovery and productivity** | | | | | | | |
| 4 | 14.3 | 122 | 38 | 16.8 | 92.5 | 11.8 | 90.4 | 23.59 | 79.52 | 2040.41 |
| 4 | 14.3 | 91.5 | 30 | 19.8 | 93.2 | 13.3 | 90.2 | 18.11 | 61.13 | 2004.36 |
| 4 | 14.3 | 73.2 | 26 | 22.9 | 93.4 | 14.5 | 90.5 | 15.95 | 53.76 | 2115.27 |
| 46.2 - 45.8 psi | **30 mL/min** | **30,40,50 mL/min** | **High purging flow rate yields to higher O2 recovery and productivity** | | | | | | | |
| ***4*** | ***9.5*** | ***122*** | ***38*** | ***21.5*** | ***90.2*** | ***13.1*** | ***88.1*** | ***28.26*** | ***95.26*** | ***2530.88*** |
| ***4*** | ***9.5*** | ***91.5*** | ***30*** | ***25.8*** | ***90.5*** | ***15.5*** | ***87.4*** | ***25.24*** | ***85.22*** | ***2921.86*** |
| ***4*** | ***9.5*** | ***73.2*** | ***26*** | ***29.5*** | ***90.4*** | ***16.3*** | ***86.5*** | ***20.57*** | ***69.35*** | ***2879.55*** |

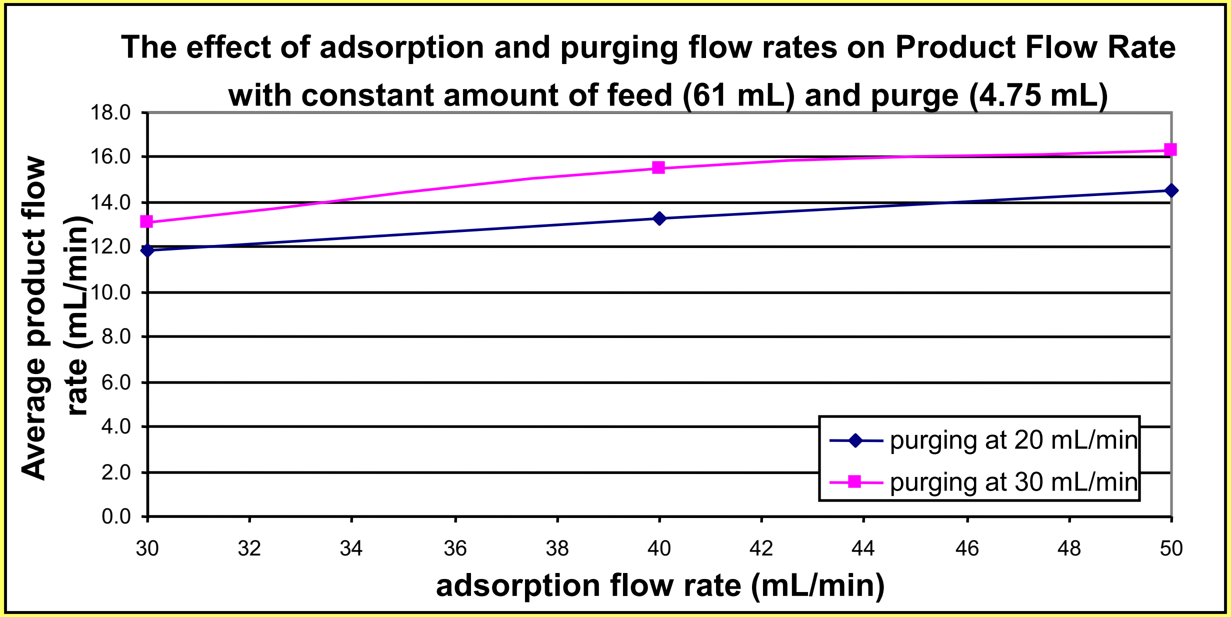
# System A: Results (III)



# System A: Results (IV)



# More Stringent Methodology to Characterization System B

System B: Results (I)

**1.**

**Start with the highest pressure, highest feed and purge flow rates**

- 45 psi
- 30 mL/min air feed
- 30 mL/min purge flow
- 15 sec depressurization

**Results:**

- Cannot produce positive adsorption results
- Gradual narrowing of production band

**2.**

**Reduce feed flow rate**

- 45 psi
- **15 mL/min air feed**
- 30 mL/min purge flow
- 15 sec depressurization

**Results:**

- The problem of narrowing production band is eliminated

3.

**Is further reduction of feed flow rate better?**

- 45 psi
- **10 mL/min air feed**
- 30 mL/min purge flow
- 15 sec depressurization

System B: Results (II)

**Results:**

- Improved O2 recovery and productivity
- Considering mass spectrometer sensitivity, 10 mL/min is the minimum feed flow rate suitable for the PSA system

4.

**Reduce purge flow rate**

- 45 psi
- 10 mL/min air feed
- **10 mL/min purge flow**
- 15 sec depressurization

System B: Results (III)

**Results:**

- Improved O2 recovery and productivity
- Obtain positive adsorption results

**5.**

## Is further reduction of purge flow rate better?

- 45 psi
- 10 mL/min air feed
- **5 mL/min purge flow**
- 15 sec depressurization

**Results:**

- Improved O2 recovery and productivity
- Obtain the best adsorption results for small diameter spiral bed

System B: Results (III)

**6.**

## Reduce depressurization time

- 45 psi
- 10 mL/min air feed
- 10 mL/min purge flow
- **5 sec depressurization**

**Results:**

- Improved O2 recovery and productivity because of lesser product loss
- But cannot give positive adsorption results due to incomplete desorption of nitrogen gas from the bed

System B: Results (IV)

7.

**Can higher purge flow rate help to clean the bed better?**

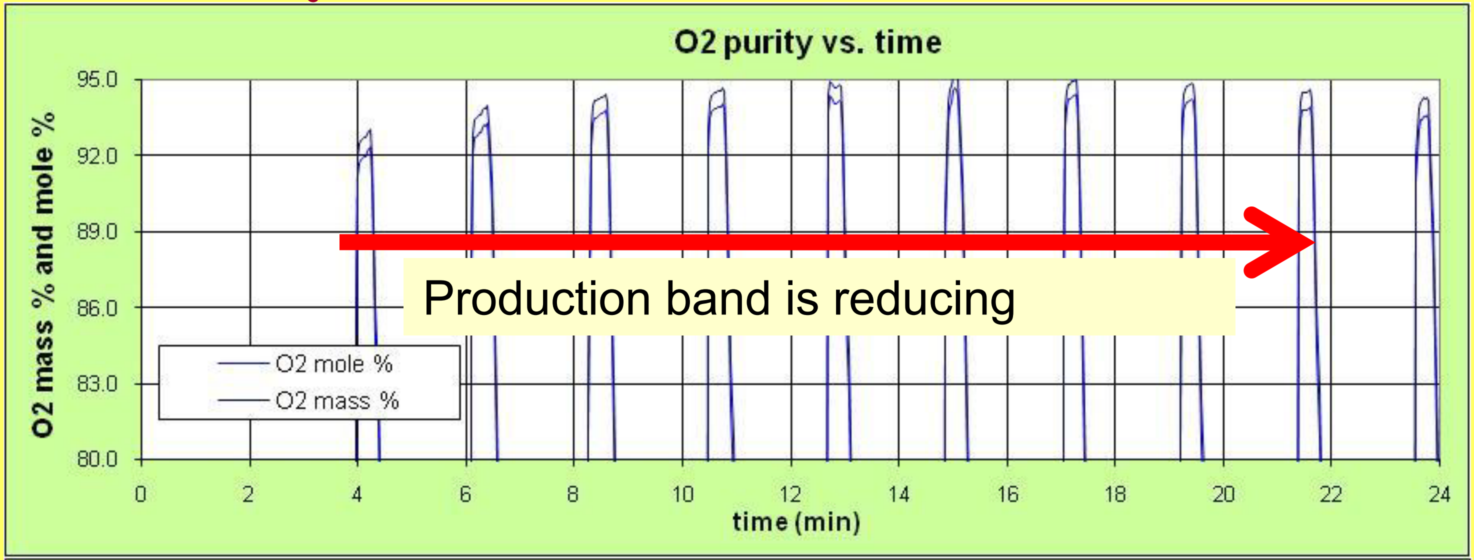
- 45 psi
- 10 mL/min air feed
- **20 mL/min and 30 mL/min purge flow**
- 5 sec depressurization

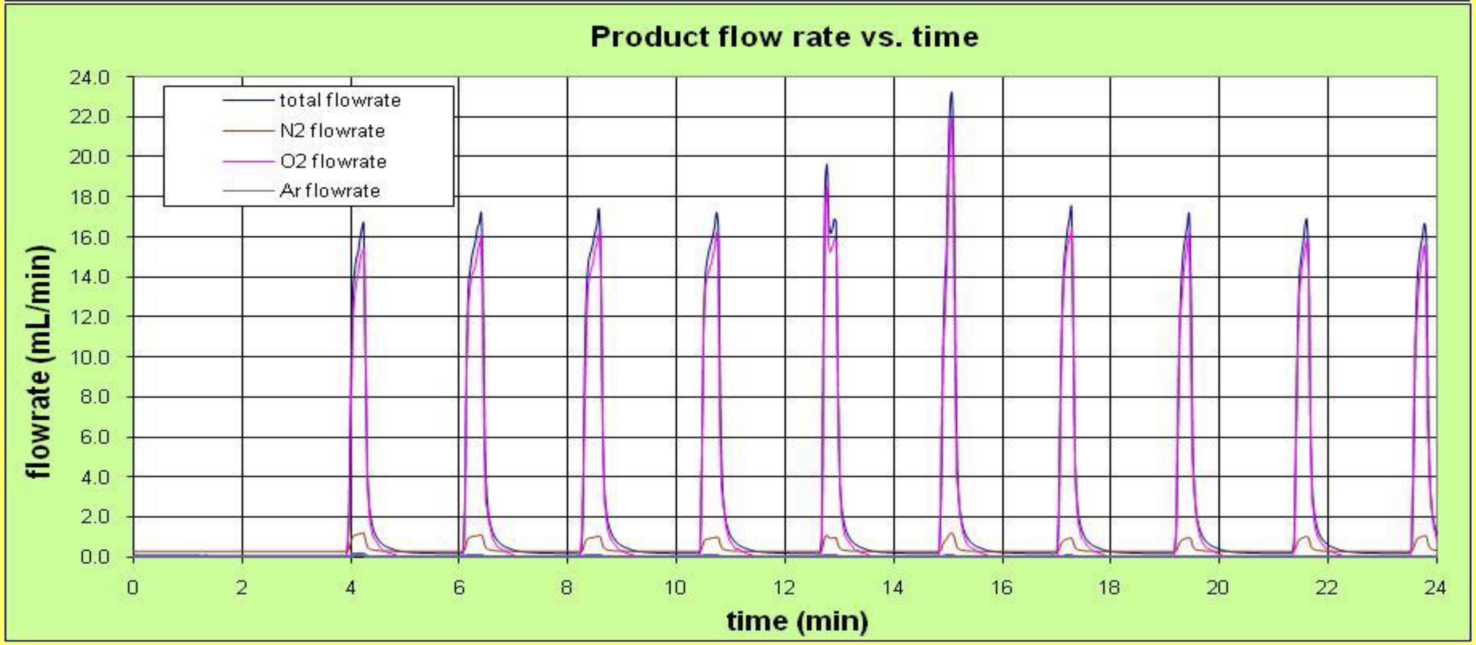
**Results:**

- The bed is not properly cleaned at high purge flow rate and is exhausted

System B: Results (V)

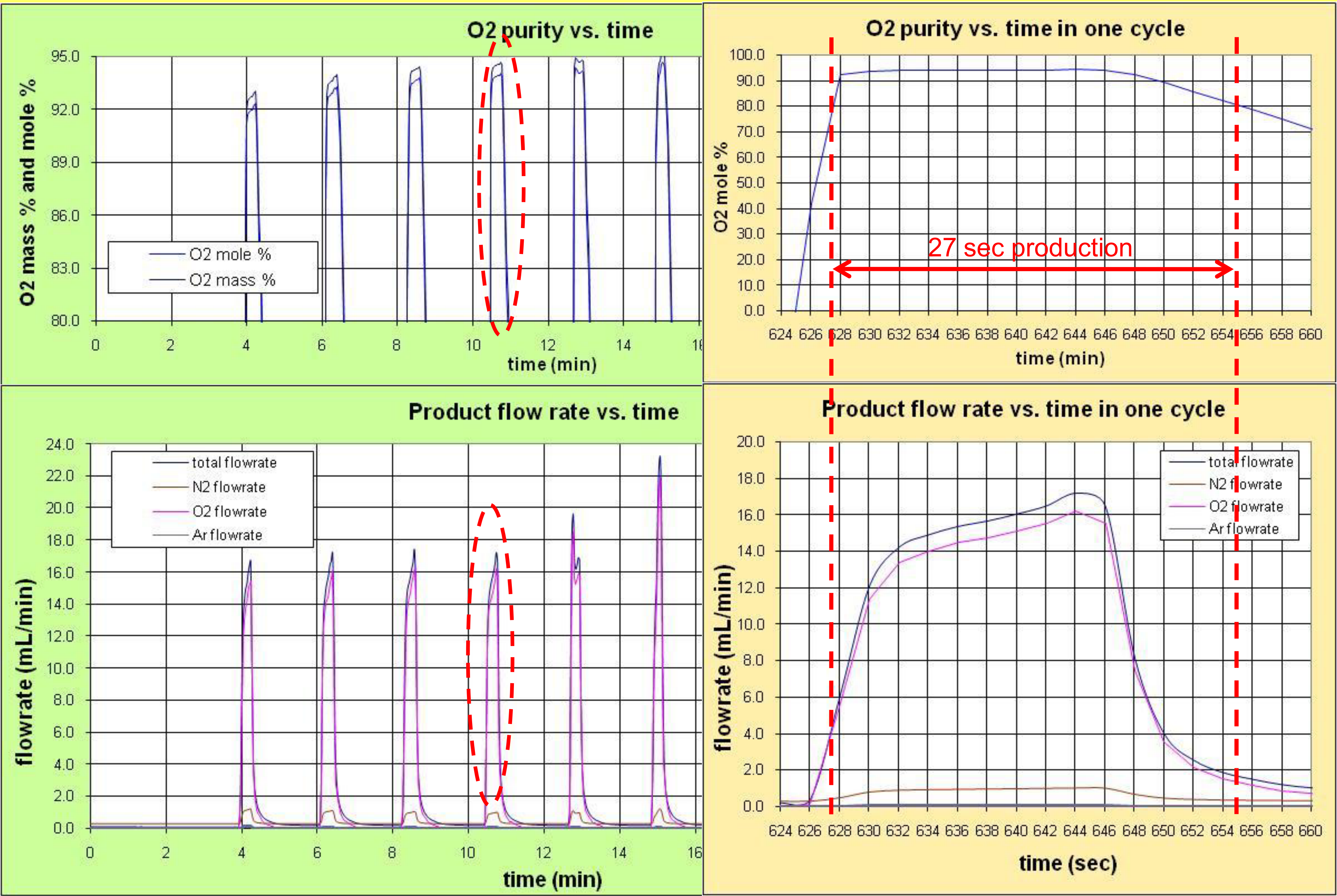
# System B: Results (I)



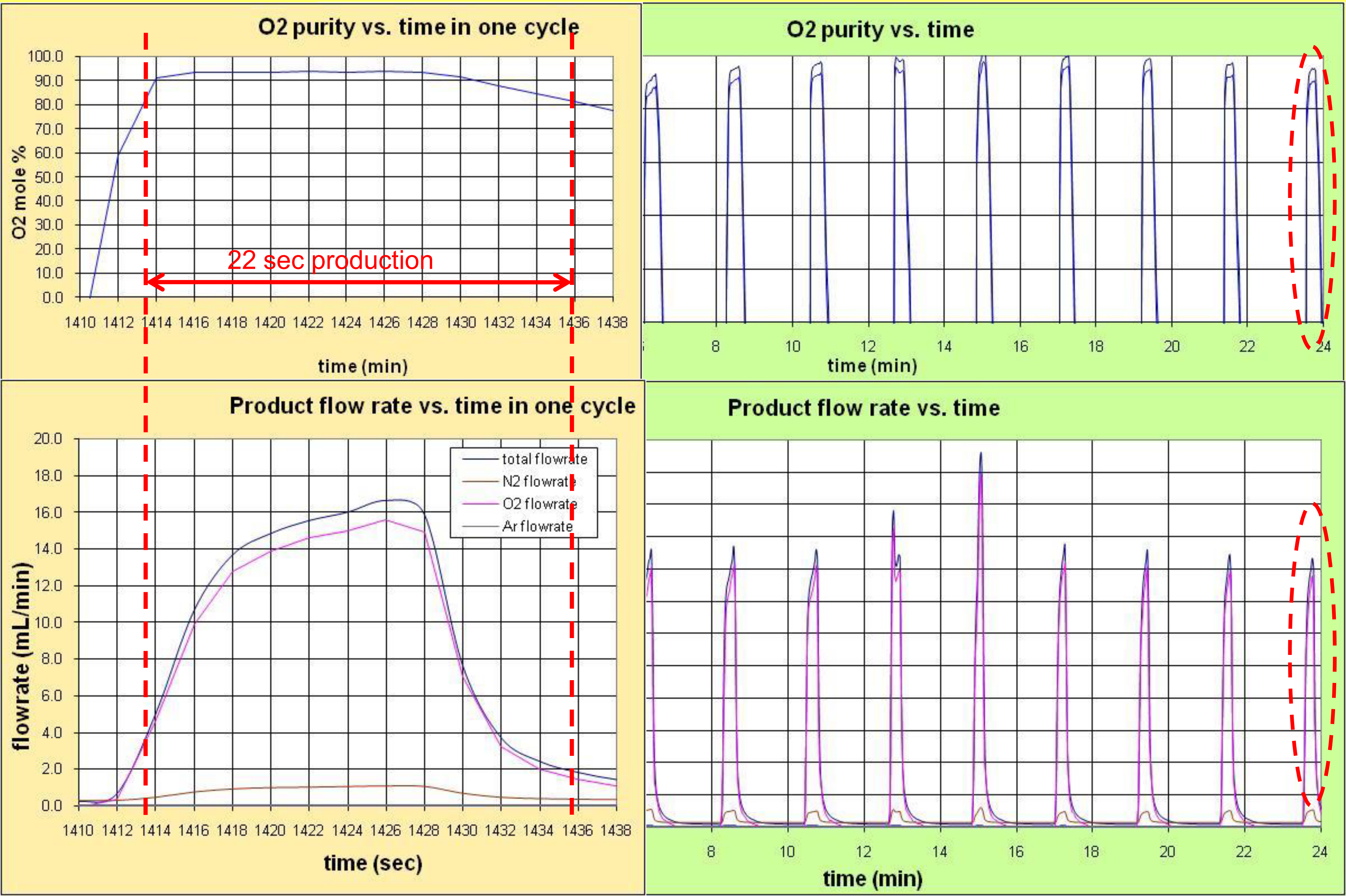




**High flow rate of feed air is not encouraged**

# System B: Results (I)

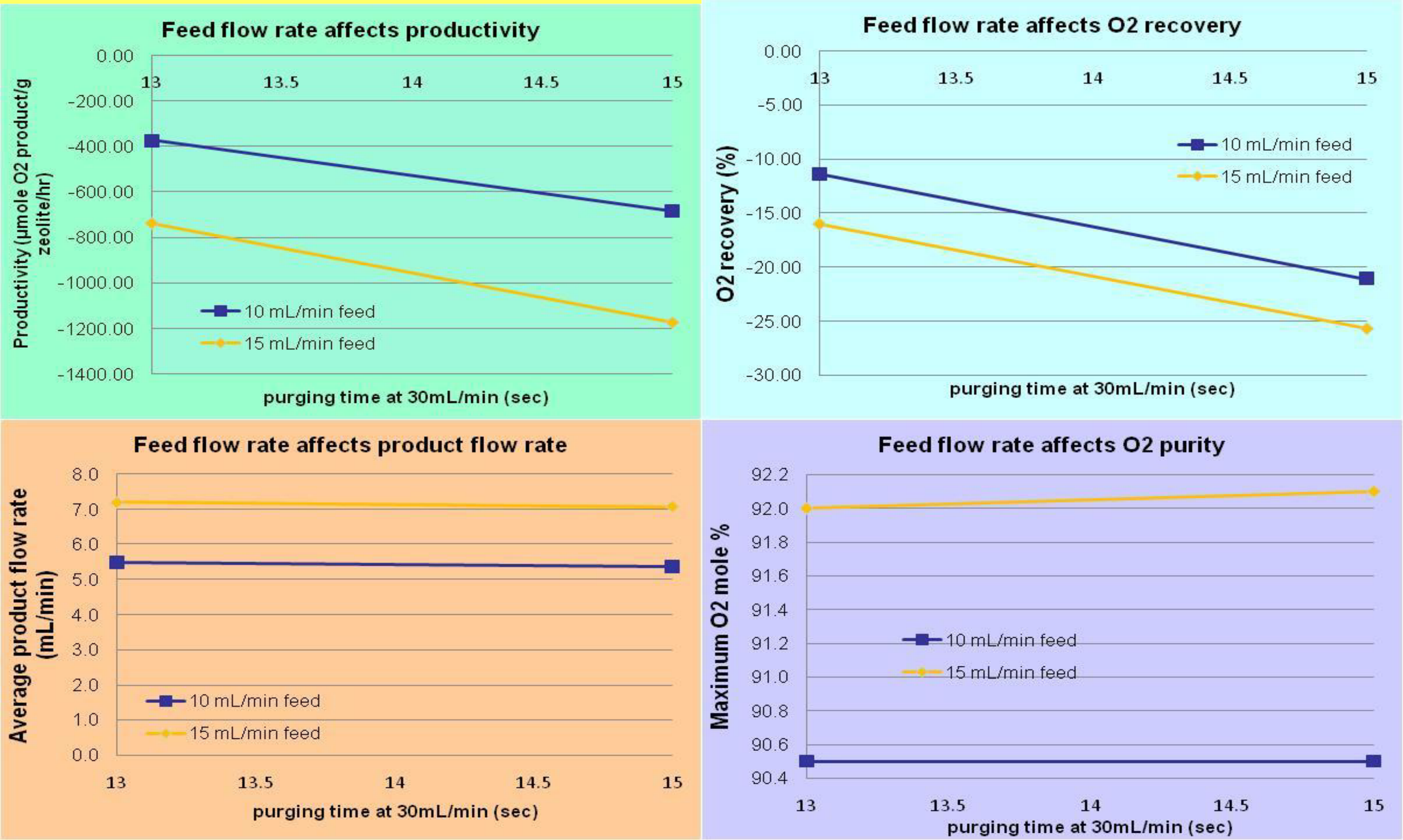


# System B: Results (I)



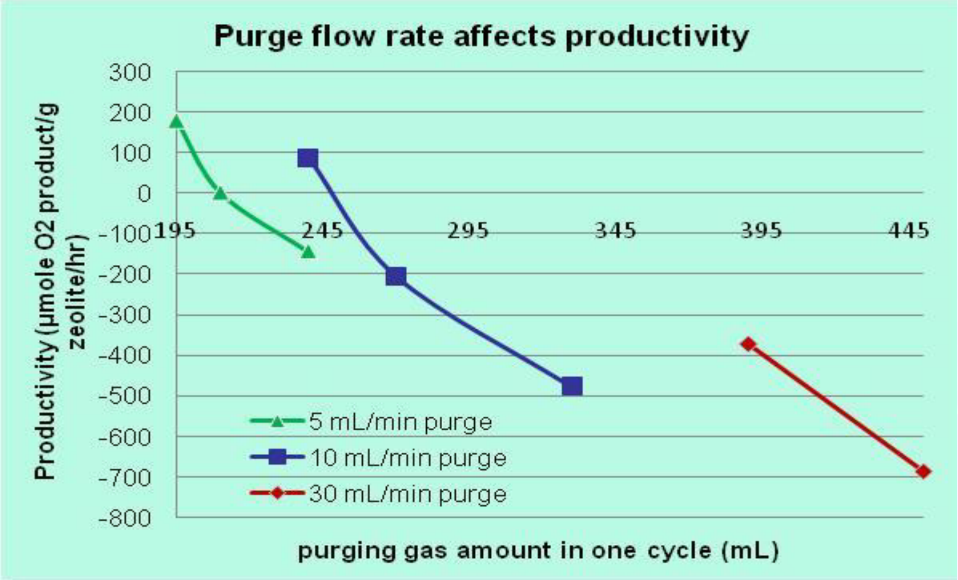
# System B: Results (II)

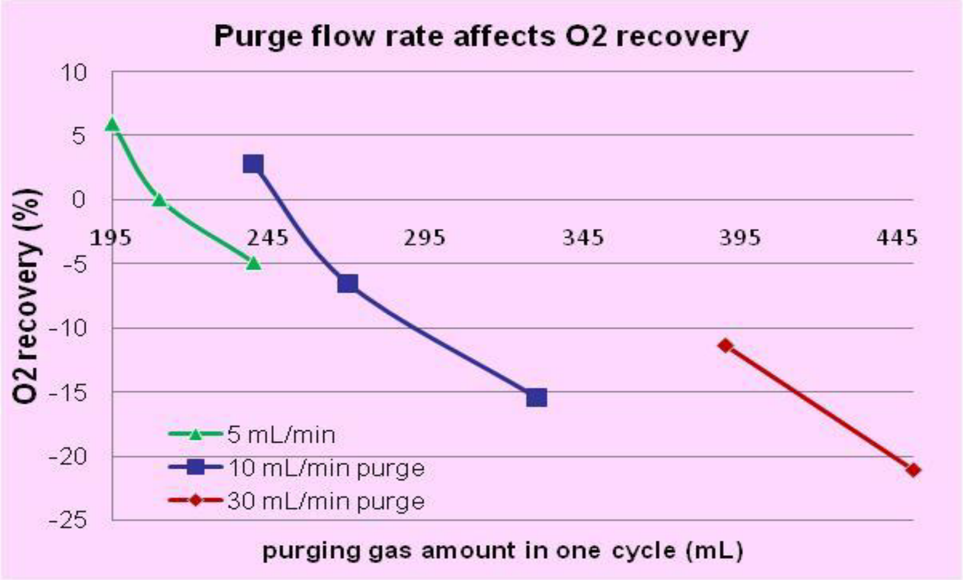
## High flow rate of feed air is not encouraged

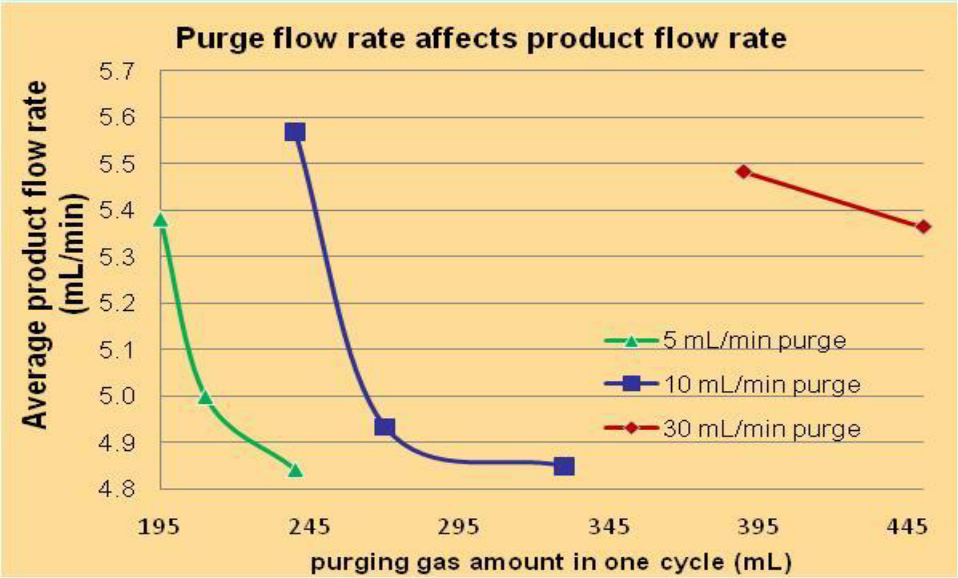


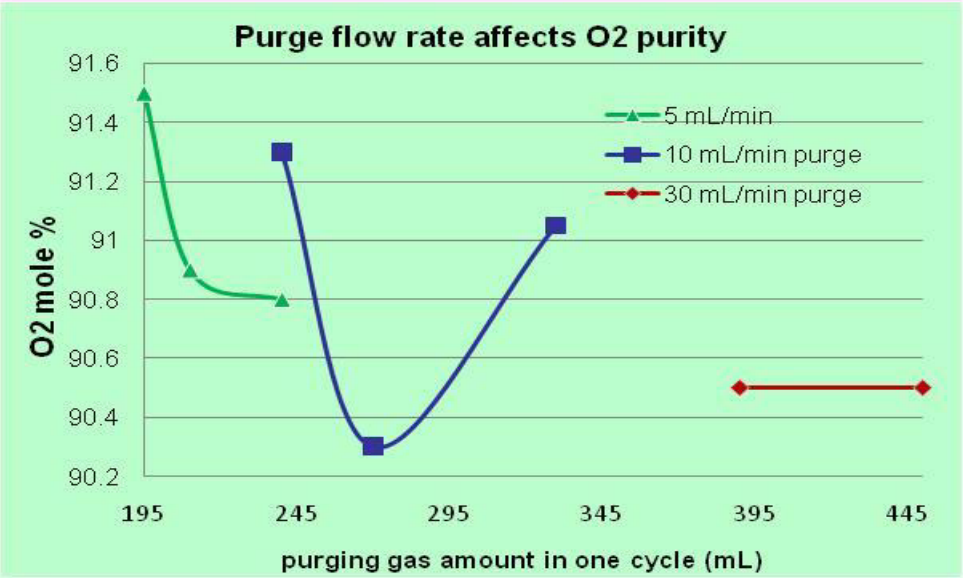
# System B: Results (III)

## High flow rate of purge gas is not encouraged



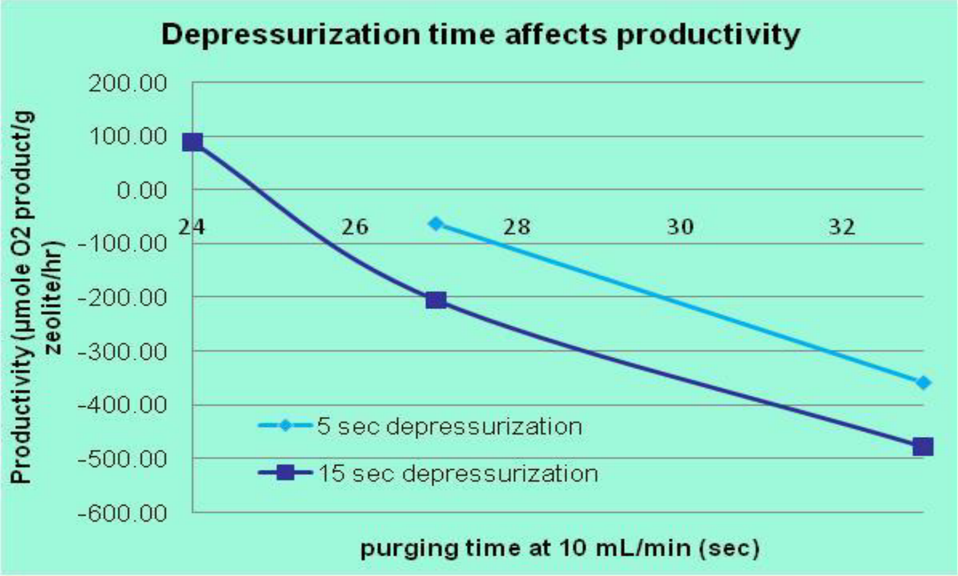



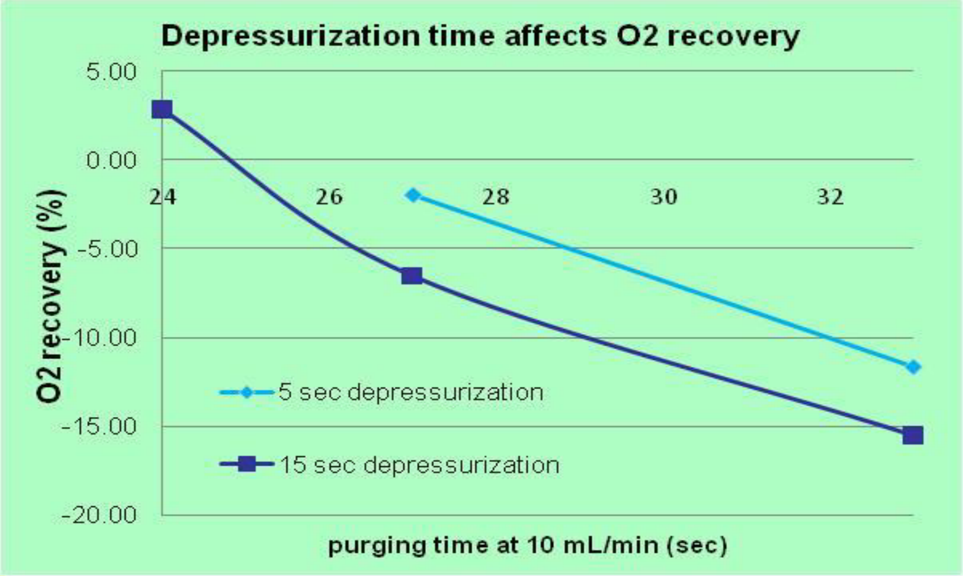



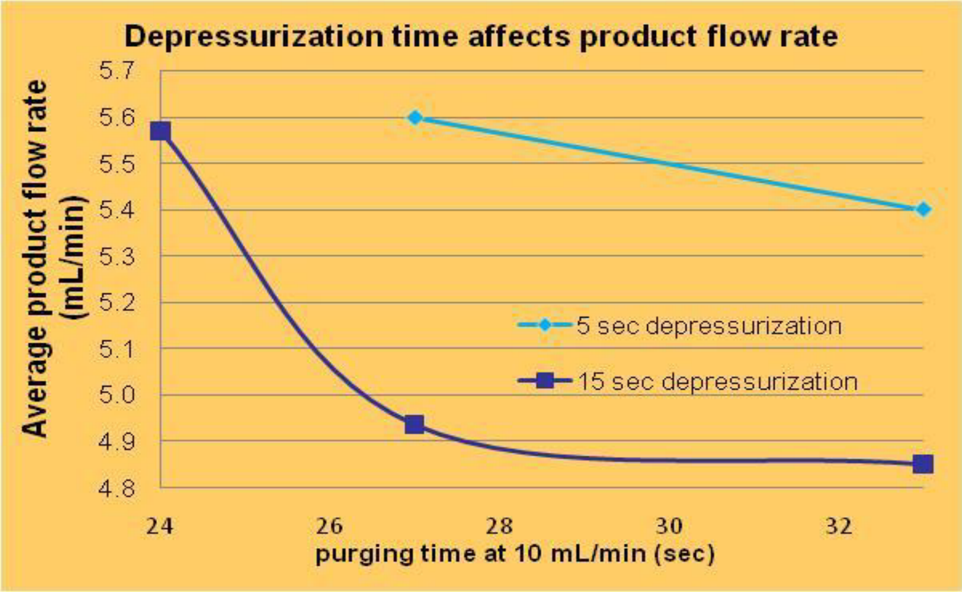



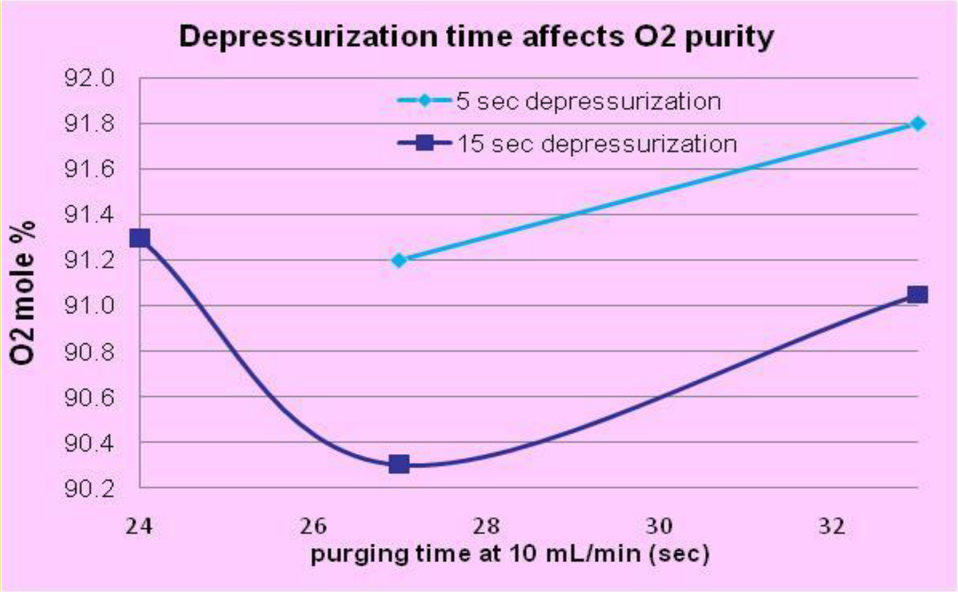
# System B: Results (IV)

**Short depressurization time is not encouraged**



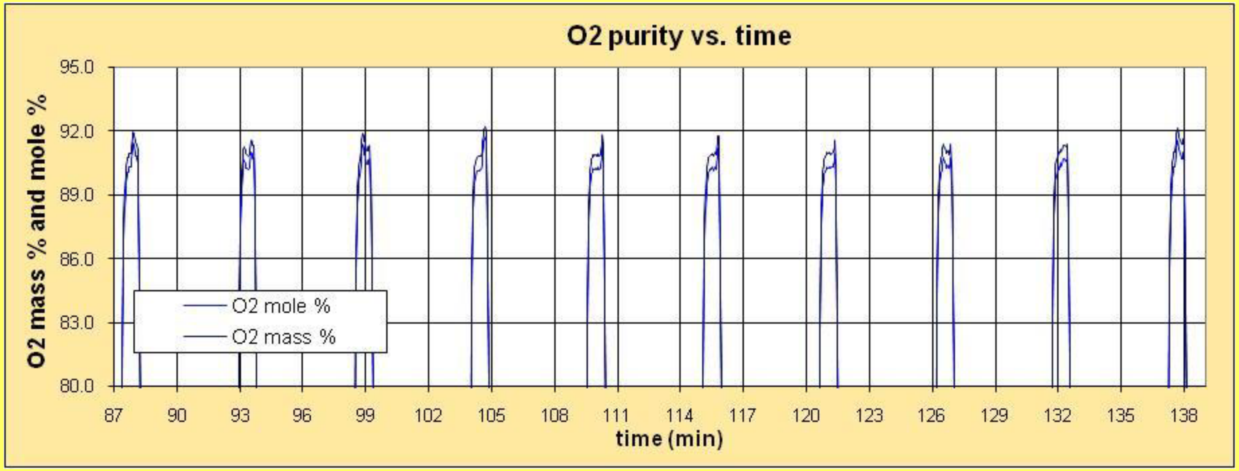



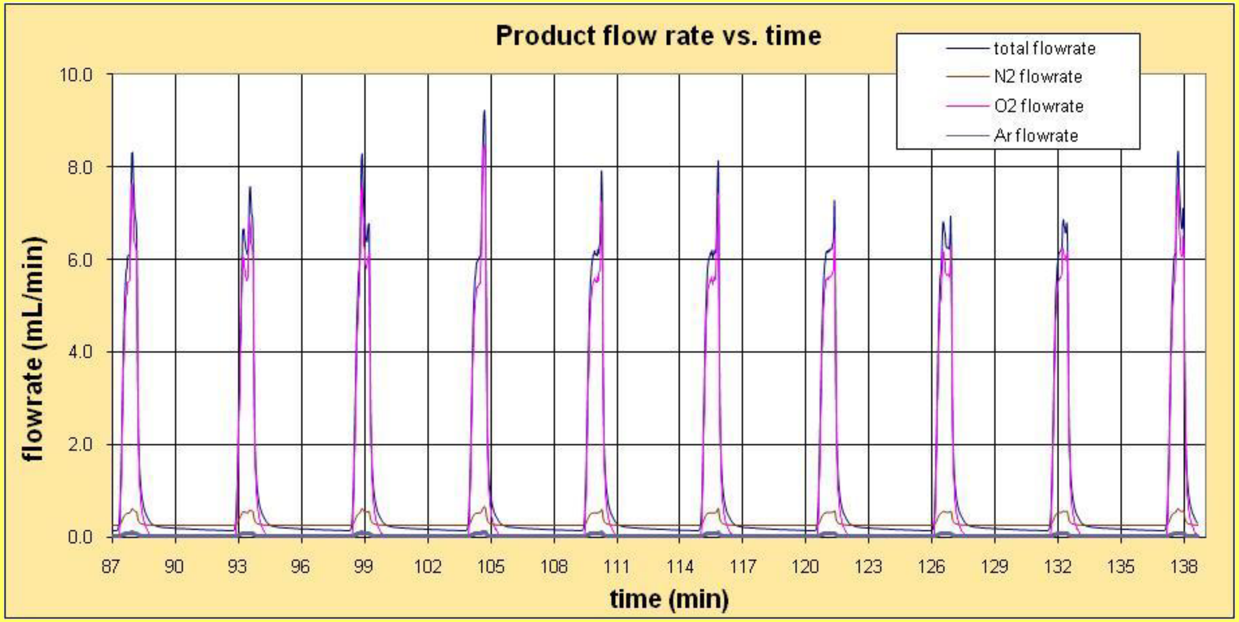



# System B: Results (V)

**27 sec purging at 10 mL/min:**

With low flow rate of purging, the bed is sustained for long time.

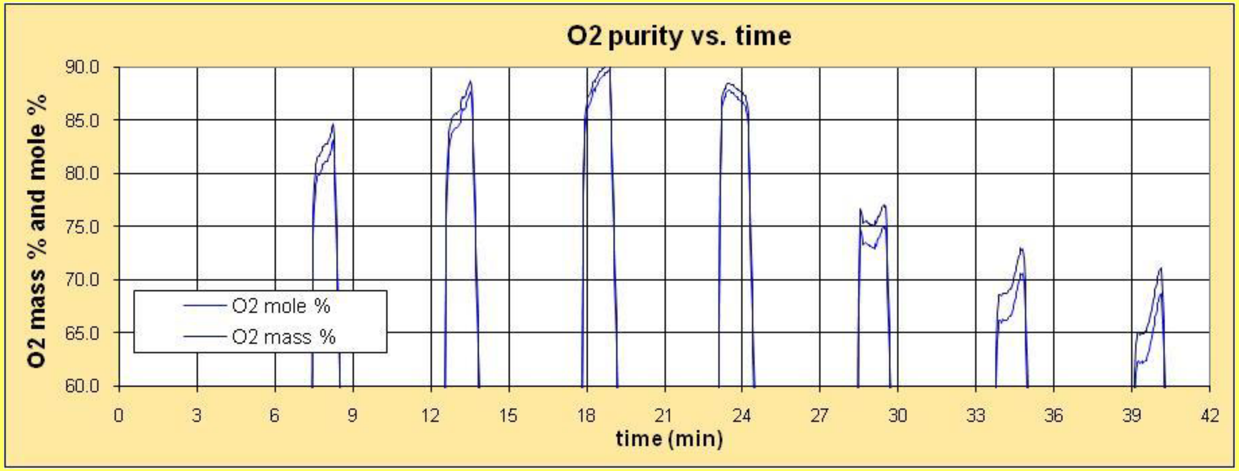


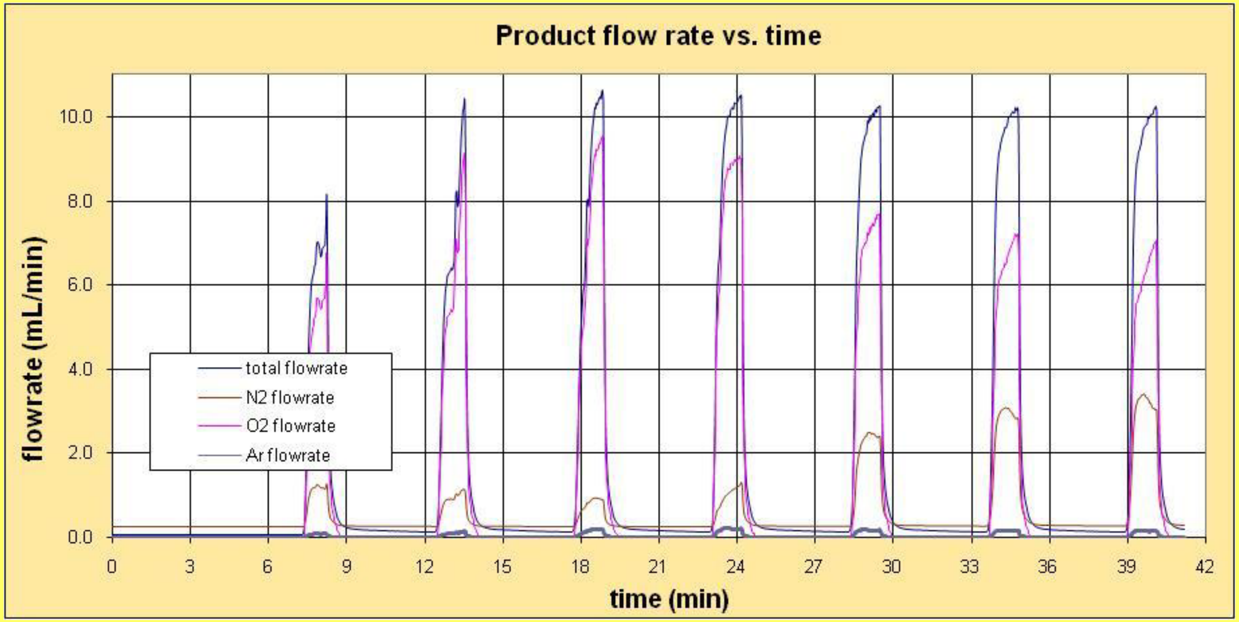



# System B: Results (V)

**<u>13.5 sec purging at 20 mL/min:</u>**

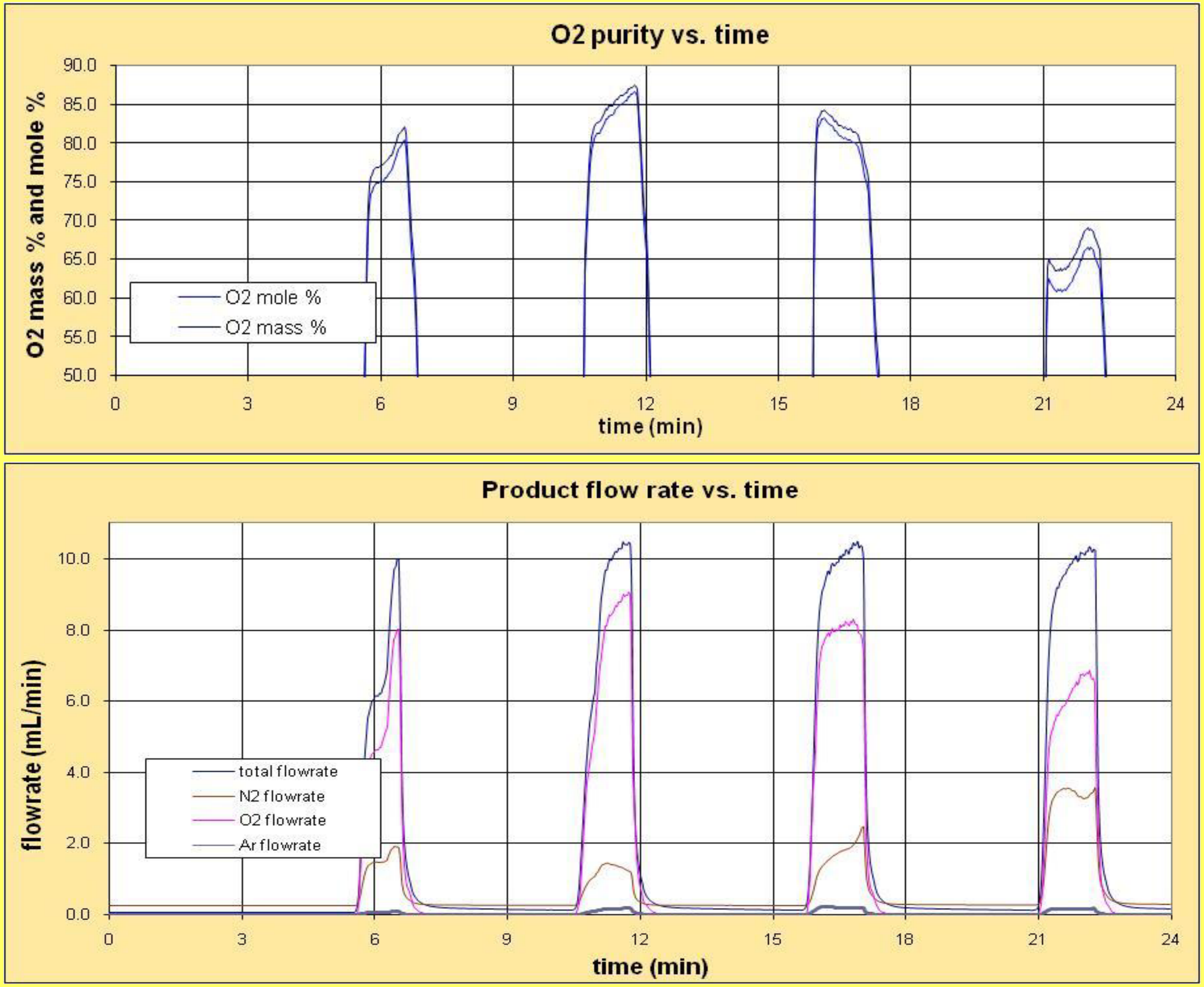
With higher flow rate of purging, the bed is exhausted in 3 cycles.



# System B: Results (V)

**9 sec purging at 30 mL/min:**
With highest flow rate of purging, the bed is exhausted in 2 cycles.




**High flow rate of purge gas is not encouraged**

# Overall results of System B (17 - 22 September 2008)

| amount of purging gas (mL) | Depressurization time (sec) | Purging time (sec) | Pressurization and Adsorption time (sec) | Production time (sec) | Maximum mL/min | Maximum mole % | Average mL/min | Average mole % | O2 recovery (%) | Productivity (µmole O2 product/g zeolite/cycle) | Productivity (µmole O2 product/g zeolite/hr) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 46 - 45 psi | 30 mL/min | 30 mL/min | **No matter how high the adsorption pressure is, spiral bed with small diameter cannot produce positive results. Moreover, the bed cannot sustain high feed flow rate (production band is narrowed)** | | | | | | | |
| | 15 | 15 | 100 | | | | | | | | |
| | 46 - 45 psi | 30 mL/min | **15 mL/min** | **eliminate the narrowed production band problem : lower feed flow rate is better** | | | | | | | |
| 450 | 15 | 15 | 200 | 40 | 9.8 | 92.1 | 7.1 | 89.9 | -25.64 | -74.88 | -1172.03 |
| 390 | 15 | 13 | 200 | 40 | 9.7 | 92.0 | 7.2 | 90.1 | -16.03 | -46.80 | -739.00 |
| 330 | *15* | *11* | *200* | *exhausted* | | | | | | | |
| | 46 - 45 psi | 30 mL/min | **10 mL/min** | **further lower feed flow rate is better** | | | | | | | |
| 450 | 15 | 15 | 300 | 60 | 6.6 | 90.5 | 5.4 | 88.7 | -21.08 | -62.82 | -685.33 |
| 390 | 15 | 13 | 300 | 60 | 6.6 | 90.5 | 5.5 | 88.9 | -11.39 | -33.93 | -372.41 |
| 330 | *15* | *11* | *300* | *exhausted* | | | | | | | |
| | 46 - 45 psi | **10 mL/min** | 10 mL/min | **lower purge flow rate is better** | | | | | | | |
| 330 | 15 | 33 | 300 | 48 | 6.4 | 91.05 | 4.9 | 88.4 | -15.48 | -46.15 | -477.33 |
| 270 | 15 | 27 | 300 | 48 | 6.3 | 90.3 | 4.9 | 88.1 | -6.53 | -19.45 | -204.72 |
| 240 | *15* | *24* | *300* | *50* | *9.3* | *91.3* | *5.6* | *88.5* | *2.82* | *8.4* | *89.15* |
| 210 | *15* | *21* | *300* | *exhausted* | | | | | | | |
| | 46 - 45 psi | **5 mL/min** | 10 mL/min | **further lower purge flow rate is better** | | | | | | | |
| 240 | 15 | 48 (24) | 300 | 42 | 6.4 | 90.8 | 4.8 | 88.4 | -4.84 | -14.72 | -142.98 |
| 210 | **15** | **42 (21)** | **300** | **42** | **7.8** | **90.9** | **5.0** | **88.0** | **0.07** | **0.21** | **2.16** |
| 195 | *15* | *39 (19.5)* | *300* | *44* | *9.4* | *91.5* | *5.4* | *88.3* | *5.94* | *17.72* | *180.16* |
| 180 | *15* | *36 (18)* | *300* | *exhausted* | | | | | | | |
| | 46 - 45 psi | **10,20,30** | 10 mL/min | **high purge flow rate is not good (cannot clean the bed as 10mL/min can do)** | | | | | | | |
| 270 | 5 | 27 | 300 | 48 | 6.8 | 90.7 | 5.6 | 89.2 | -3.19 | -9.50 | -100.03 |
| 270 | *5* | *13.5* | *300* | *exhausted* | | | | | | | |
| 270 | *5* | *9* | *300* | *exhausted* | | | | | | | |
| | 46 - 45 psi | 10 mL/min | 10 mL/min | **shorter depressurization time has lower product loss, thus it is better** | | | | | | | |
| 330 | **5** | 33 | 300 | 48 | 6.4 | 91.3 | 5.4 | 89.5 | -13.97 | -41.64 | -430.72 |
| 270 | **5** | 27 | 300 | 48 | 6.8 | 90.7 | 5.6 | 89.2 | -3.19 | -9.50 | -100.03 |
| 240 | ***5*** | *24* | *300* | *exhausted* | | | | | | | |

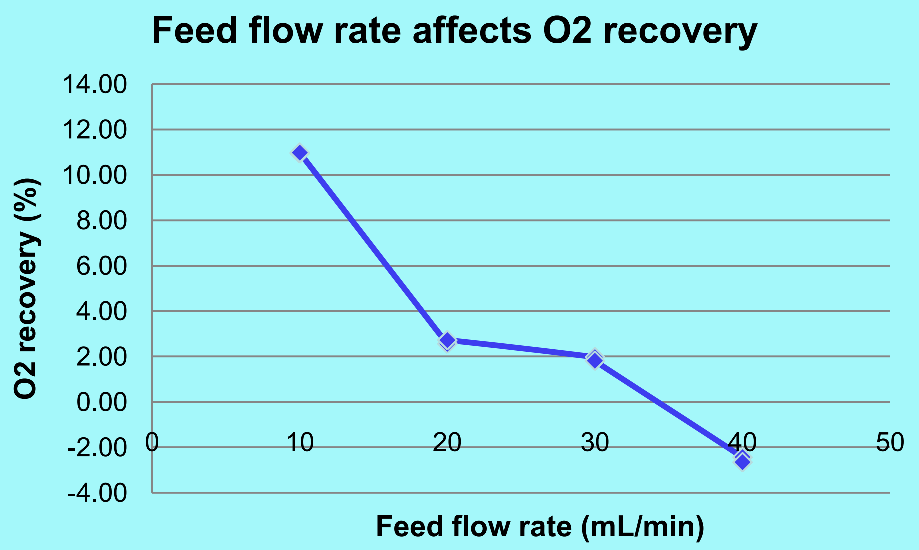
# Overall results of System B (24 - 26 September 2008)

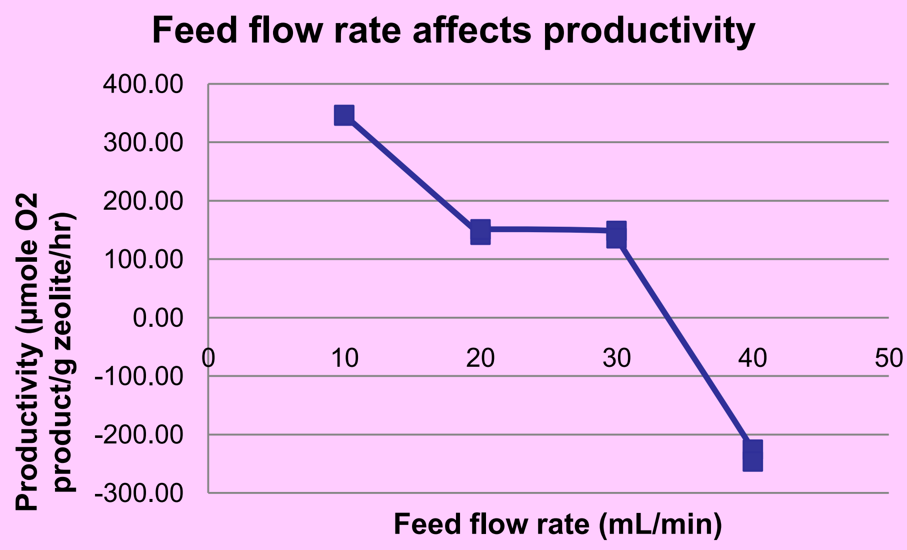
| amount of purging gas (mL) | Depressurization time (sec) | Purging time (sec) | Pressurization and Adsorption time (sec) | Production time (sec) | Maximum | | Average | | O2 recovery (%) | Productivity (µmole O2 product/g zeolite/cycle) | Productivity (µmole O2 product/g zeolite/hr) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | mL/min | mole % | mL/min | mole % | | | |
| | 45.2 - 44.6 psi | 10 mL/min | **30 mL/min** | **high feed flow rate** | | | | | | | |
| 240 | 15 | 24 | 100 | 16 | 13.6 | 92.2 | 7.4 | 87.9 | -14.90 | -41.72 | -1080.44 |
| 180 | 15 | 18 | 100 | 16 | 14 | 92.2 | 7.5 | 85.5 | -6.26 | -17.53 | -474.52 |
| 150 | *15* | *15* | *100* | *exhausted* | | | | | | | |
| 120 | *15* | *12* | *100* | *exhausted* | | | | | | | |
| | 45.2 - 44.6 psi | 10 mL/min | **20 mL/min** | **lower feed flow rate is better** | | | | | | | |
| 330 | 15 | 33 | 150 | 22 | 10.8 | 92.4 | 6.5 | 88.7 | -24.17 | -68.36 | -1242.86 |
| 300 | 15 | 30 | 150 | 22 | 10.8 | 92.3 | 6.7 | 89.0 | -19.18 | -54.25 | -1001.59 |
| 240 | 15 | 24 | 150 | 24 | 11 | 92.4 | 6.5 | 88.1 | -9.80 | -27.71 | -527.90 |
| 180 | **15** | **18** | **150** | **24** | **11.8** | **91.8** | **6.9** | **87.9** | **0.19** | **0.54** | **10.55** |
| 150 | *15* | *15* | *150* | *exhausted* | | | | | | | |
| 120 | *15* | *12* | *150* | *exhausted* | | | | | | | |
| | 45.2 - 44.6 psi | 10 mL/min | **10 mL/min** | **further lower feed flow rate is better** | | | | | | | |
| 240 | 15 | 24 | 300 | 38 | 6.00 | 90.30 | 4.31 | 87.70 | -9.58 | -27.78 | -294.98 |
| 210 | 15 | 21 | 300 | 40 | 6.15 | 90.25 | 4.54 | 87.70 | -2.96 | -8.58 | -91.93 |
| 195 | **15** | **19.5** | **300** | **42** | **7.20** | **90.33** | **4.89** | **87.70** | **2.35** | **6.82** | **73.37** |
| 180 | *15* | *18* | *300* | *exhausted* | | | | | | | |
| | 45.2 - 44.6 psi | **5 mL/min** | 10 mL/min | **lower purge flow rate is NOT better** | | | | | | | |
| 195 | 15 | 39 | 300 | 36 | 6.45 | 90.7 | 4.4 | 87.5 | -4.26 | -12.34 | -125.50 |
| 165 | 15 | 33 | 300 | 36 | 6.3 | 90.1 | 4.5 | 87.5 | 0.51 | 1.48 | 15.26 |
| 150 | **15** | **30** | **300** | **34** | **6.85** | **90.35** | **4.5** | **87.3** | **1.17** | **3.40** | **35.53** |
| 135 | *15* | *27* | *300* | *exhausted* | | | | | | | |
| | 45.2 - 44.6 psi | 5 mL/min | **5 mL/min** | **further lower feed flow rate is NOT better** | | | | | | | |
| 180 | *15* | *36* | *600* | *exhausted* | | | | | | | |
| 150 | *15* | *30* | *600* | *exhausted* | | | | | | | |
| 120 | *15* | *24* | *600* | *exhausted* | | | | | | | |
| | 45.2 - 44.6 psi | 10 mL/min | 10 mL/min | **shorter depressurization time is NOT better** | | | | | | | |
| 240 | ***5*** | *24* | *300* | *exhausted* | | | | | | | |
| 210 | ***5*** | *21* | *300* | *exhausted* | | | | | | | |

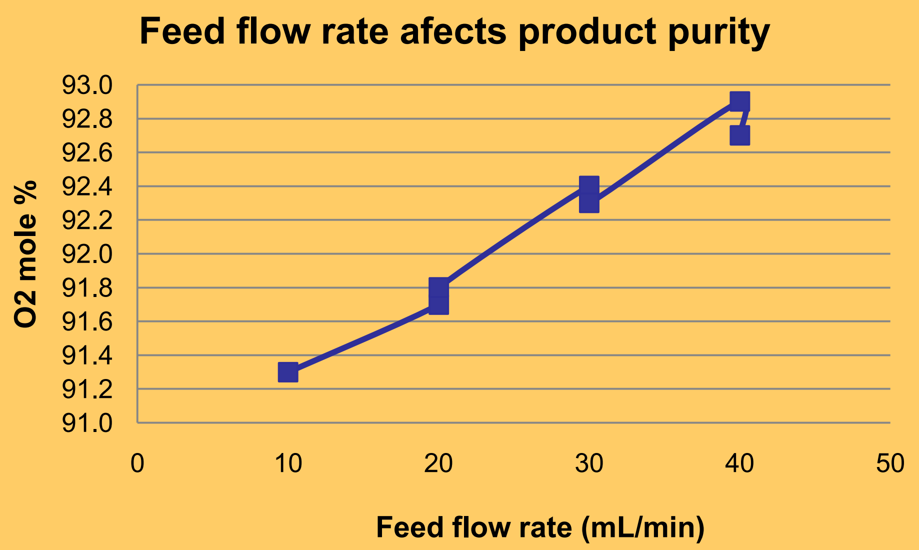
# Overall results of System B (28 - 29 September 2008)

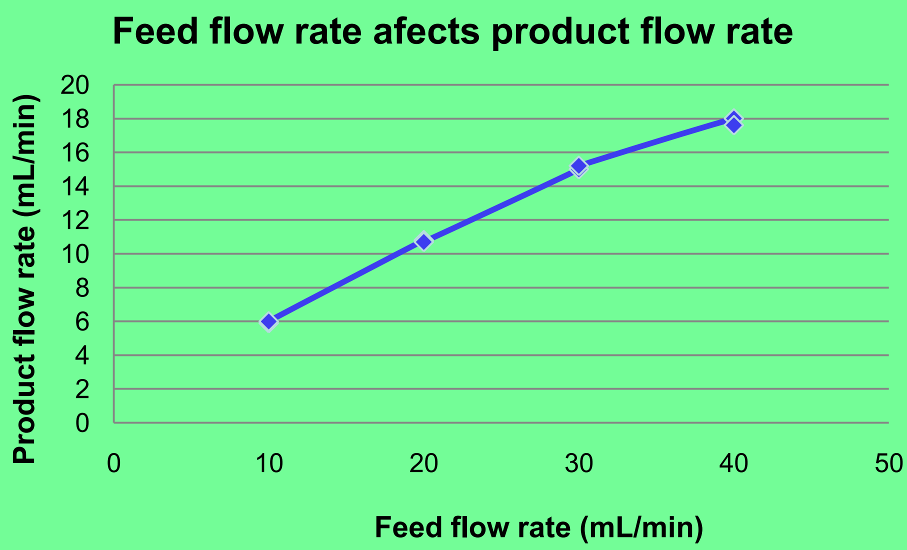
| Depressurization time (sec) | Purging time (sec) | Pressurization and Adsorption time (sec) | Production time (sec) | Maximum | | Average | | O2 recovery (%) | Productivity (µmole O2 product/g zeolite/cycle) | Productivity (µmole O2 product/g zeolite/hr) |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | mL/min | mole % | mL/min | mole % | | | |
| 46.2 - 45.8 psi | 10 mL/min | **10, 20, 30, 40 mL/min** | **Different feed flow rates: 10 mL/min is the best** | | | | | | | |
| 15 | 24 | 360 | 68 | 5.9 | 89.8 + 2.5 | 5.0 | 88.2+ 2.5 | 10.94 | 38.28 | 345.41 |
| 15 | 24 | 360 | 68 | 6 | 89.8 + 2.5 | 5.0 | 88.2 + 2.5 | 10.98 | 38.40 | 346.51 |
| 15 | 24 | 180 | 34 | 10.8 | 91.7 | 7.4 | 89.1 | 2.56 | 8.64 | 142.04 |
| 15 | 24 | 180 | 34 | 10.7 | 91.8 | 7.5 | 89.2 | 2.72 | 9.18 | 150.83 |
| 15 | 24 | 120 | 26 | 15 | 92.4 | 9.3 | 89.1 | 1.97 | 6.54 | 148.19 |
| 15 | 24 | 120 | 26 | 15.2 | 92.3 | 9.3 | 89.0 | 1.81 | 6.00 | 135.93 |
| 15 | 24 | 90 | 20 | 18 | 92.9 | 10.1 | 89.2 | -2.44 | -8.09 | -225.90 |
| 15 | 24 | 90 | 20 | 17.6 | 92.7 | 10.1 | 89.0 | -2.66 | -8.82 | -246.03 |
| 46.2 - 45.8 psi | **5, 10, 20 mL/min** | 10 mL/min | **Different purge flow rates: 10 mL/min is the best** | | | | | | | |
| 15 | 48 | 360 | 50 | 5.5 | 89.8+ 2.5 | 4.4 | 87.8+ 2.5 | -4.63 | -16.20 | -137.94 |
| 15 | 48 | 360 | 52 | 5.6 | 89.8+ 2.5 | 4.4 | 87.7+ 2.5 | -3.60 | -12.58 | -107.07 |
| 15 | 24 | 360 | 68 | 5.9 | 89.8+ 2.5 | 5.0 | 88.2+ 2.5 | 10.94 | 38.28 | 345.41 |
| 15 | 24 | 360 | 68 | 6 | 89.8+ 2.5 | 5.0 | 88.2+ 2.5 | 10.98 | 38.40 | 346.51 |
| *15* | *12* | *360* | *cannot clean the bed throroughly* | | | | | | | |
| 46.2 - 45.8 psi | 10 mL/min | 10 mL/min | **Optimization by reducing purge amount (> 80 and > 70 mole %)** | | | | | | | |
| 15 | 22 | 360 | 46 | 5.4 | 89.3+ 2.5 | 4.2 | 87.2+ 2.5 | -3.50 | -12.26 | -111.14 |
| 15 | 22 | 360 | 54 | 5.4 | 89.3+ 2.5 | 3.7 | 85.0+ 2.5 | -2.66 | -9.31 | -84.46 |
| 15 | 20 | 360 | 46 | 5.4 | 89.2+ 2.5 | 4.2 | 87.0+ 2.5 | -1.16 | -4.06 | -36.99 |
| 15 | 20 | 360 | 54 | 5.4 | 89.2+ 2.5 | 3.8 | 84.9+ 2.5 | -0.32 | -1.10 | -10.05 |
| 15 | 18 | 360 | 46 | 5.4 | 89.0+ 2.5 | 4.2 | 87.1+ 2.5 | 1.42 | 4.96 | 45.42 |
| 15 | 18 | 360 | 54 | 5.4 | 89.0+ 2.5 | 3.8 | 85.0+ 2.5 | 2.29 | 8.00 | 73.31 |
| 15 | 16 | 360 | 48 | 5.3 | 89.0+ 2.5 | 4.2 | 87.1+ 2.5 | 4.60 | 16.09 | 148.18 |
| 15 | 16 | 360 | 56 | 5.3 | 89.0+ 2.5 | 3.8 | 85.1+ 2.5 | 5.48 | 19.16 | 176.43 |
| 15 | 14 | 360 | 48 | 5.3 | 89.3+ 2.5 | 4.3 | 87.6+ 2.5 | 7.70 | 26.94 | 249.30 |
| 15 | 14 | 360 | 56 | 5.3 | 89.3+ 2.5 | 3.8 | 85.1+ 2.5 | 8.78 | 30.73 | 284.41 |
| 15 | 13 | 360 | 48 | 5.3 | 89.5+ 2.5 | 4.2 | 87.4+ 2.5 | 7.91 | 27.67 | 256.76 |
| 15 | 13 | 360 | 56 | 5.3 | 89.5+ 2.5 | 3.7 | 85.3+ 2.5 | 8.74 | 30.59 | 283.84 |
| *15* | *12* | *360* | *exhausted* | | | | | | | |
| 46.2 - 45.8 psi | 10 mL/min | 10 mL/min | **Average the results of optimization (in between 70 - 80 mole %)** | | | | | | | |
| 15 | 22 | 360 | 50 | 5.4 | 89.3+ 2.5 | 4.0 | 86.1+ 2.5 | -3.08 | -10.79 | -97.80 |
| 15 | 20 | 360 | 50 | 5.4 | 89.2+ 2.5 | 4.0 | 86.0+ 2.5 | -0.74 | -2.58 | -23.52 |
| 15 | 18 | 360 | 50 | 5.4 | 89.0+ 2.5 | 4.0 | 86.0+ 2.5 | 1.86 | 6.48 | 59.37 |
| 15 | 16 | 360 | 52 | 5.3 | 89.0+ 2.5 | 4.0 | 86.1+ 2.5 | 5.04 | 17.63 | 162.31 |
| 15 | 14 | 360 | 52 | 5.3 | 89.3+ 2.5 | 4.1 | 86.4+ 2.5 | 8.24 | 28.84 | 266.86 |
| **15** | **13** | **360** | **52** | **5.3** | **89.5**+ 2.5 | **4.0** | **86.3**+ 2.5 | **8.33** | **29.13** | **270.30** |
| 15 | 12 | 360 | *exhausted* | | | | | | | |

# System B: Results (VI)

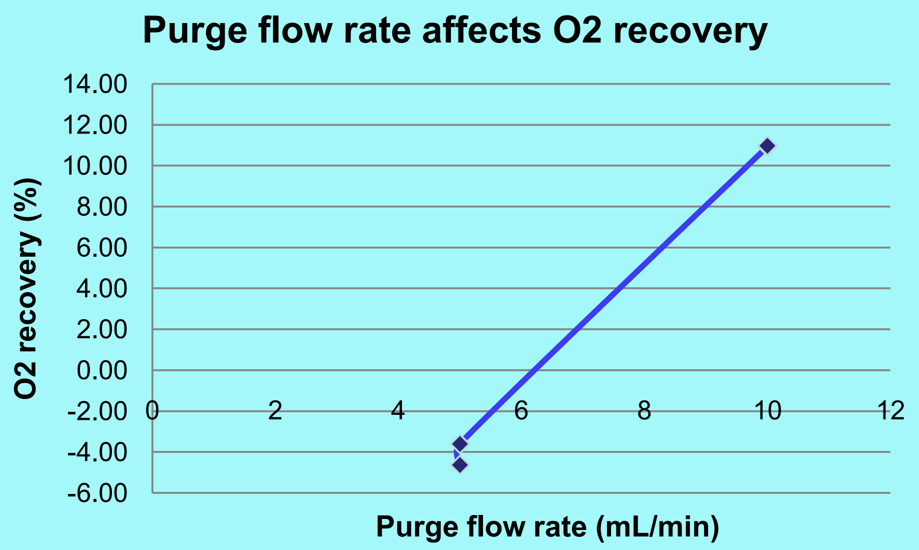


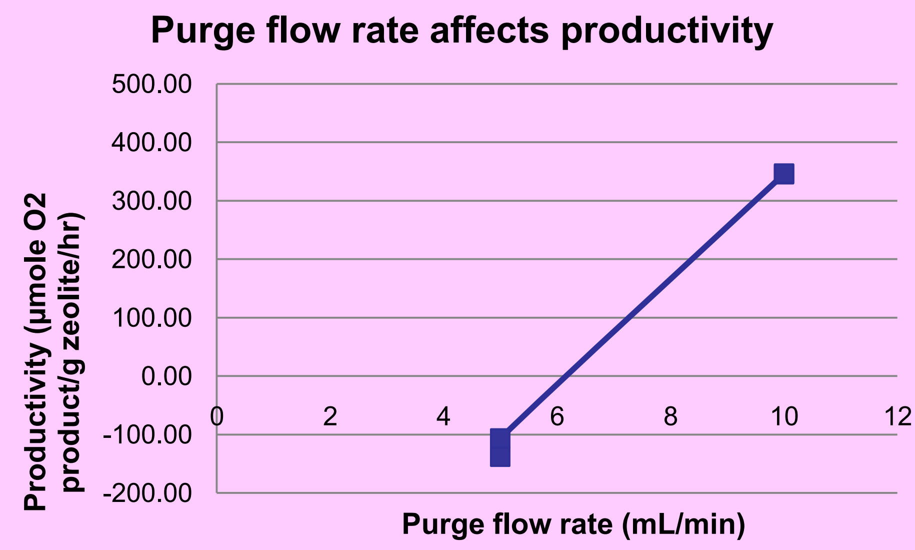



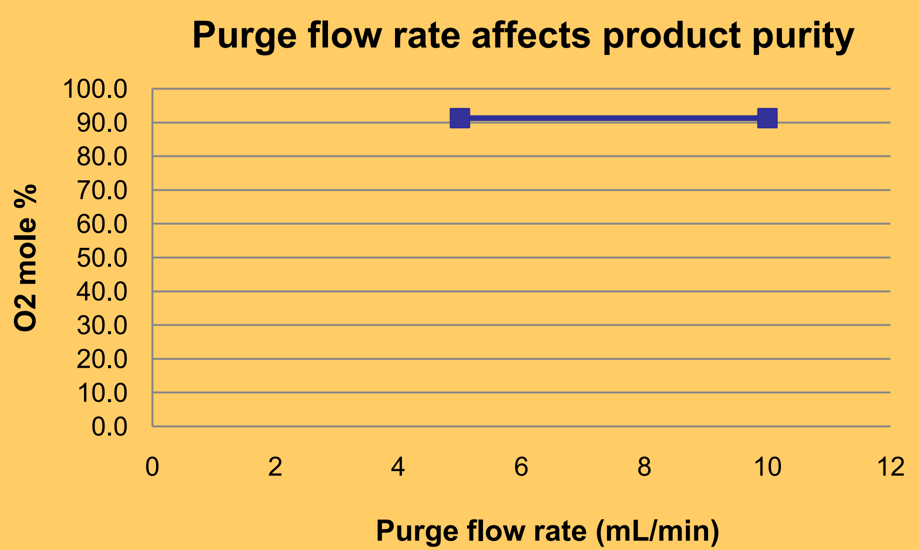



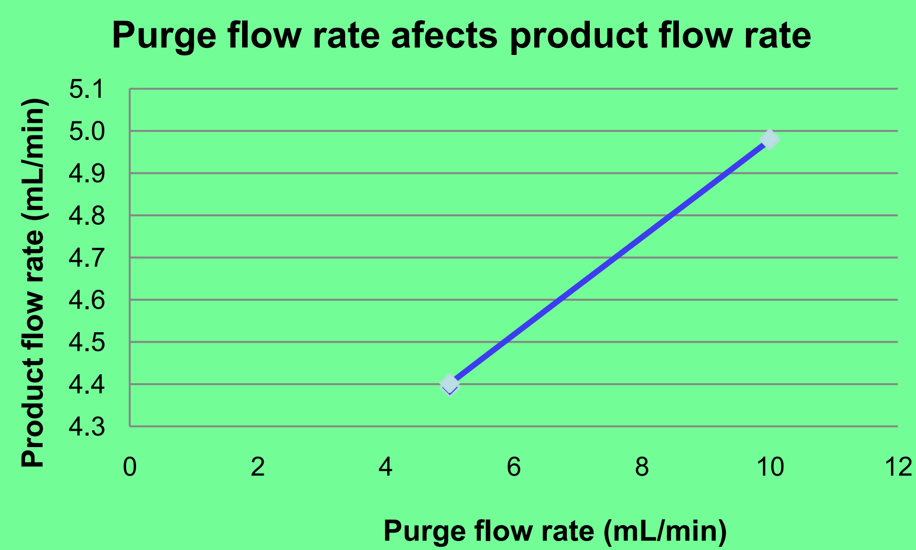



# System B: Results (VII)

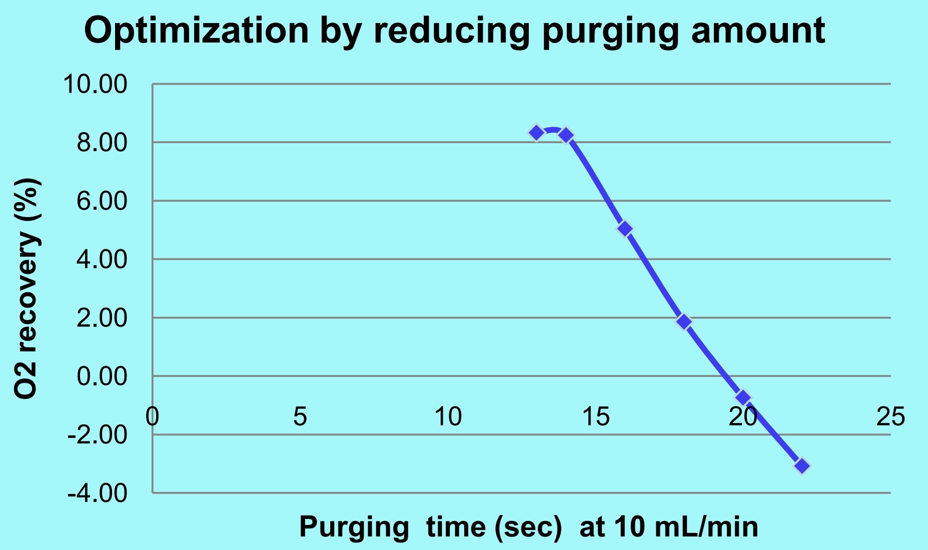


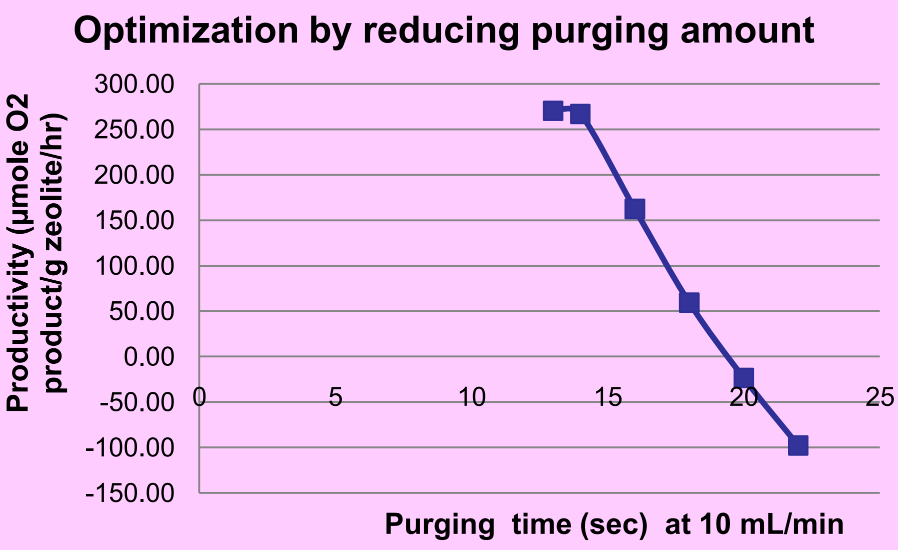



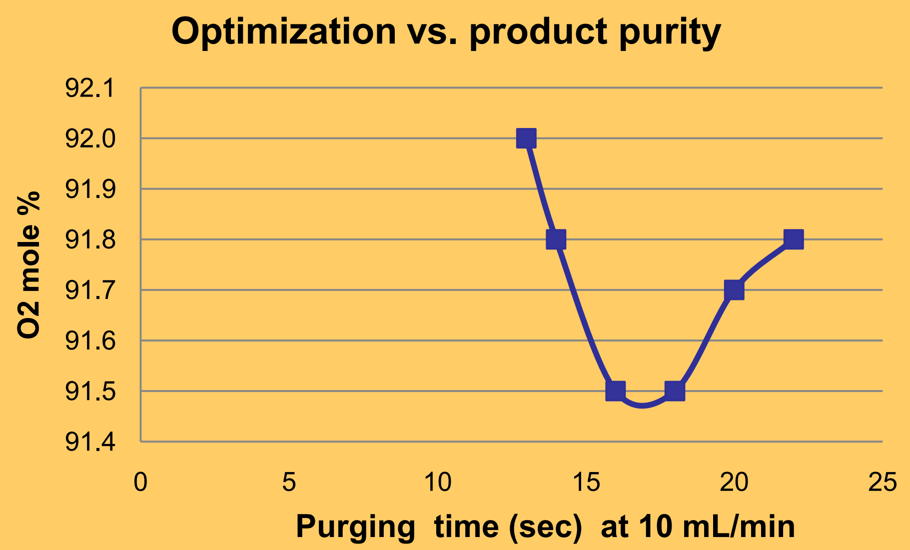



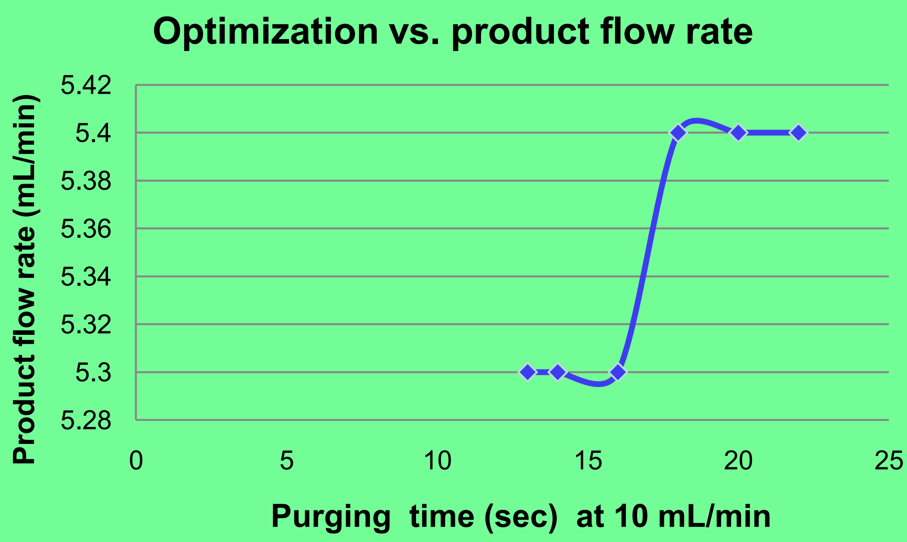



# System B: Results (VIII)



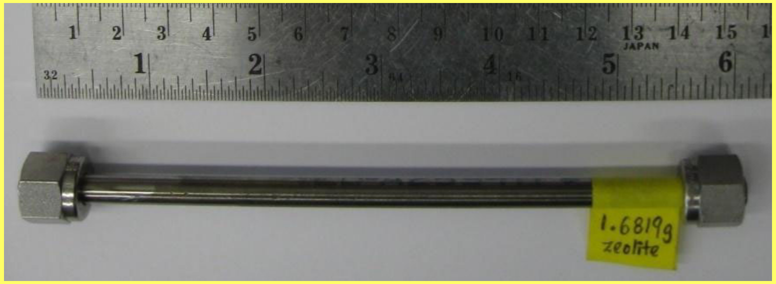



# Conclusions

## System A




**Operating conditions:**

- High feed flow rate **(30 mL/min)**
  - can fasten pressurization to increase productivity rate
- High purge flow rate **(30 mL/min)**
- Short depressurization time **(4 sec)**

**System Outputs:**

- 91.7 (max) 89.3 (ave) mole % Oxygen
- Product flow rate: 17.1 (max) 11.6 (ave) mL/min
- 23.91 % Oxygen recovery
- 80.59 µmole Oxygen/g zeolite/cycle
- 2149.03 µmole Oxygen/g zeolite/hr

## System B

**Operating conditions:**

- Low feed flow rate **(10 mL/min)**
  - can fasten pressurization to increase productivity rate
- Low purge flow rate **(10 mL/min)**
- Long depressurization time **(15 sec)**

**System Outputs:**

- 92.0 (max) 88.8 (ave) mole % Oxygen
- Product flow rate: 5.3 (max) 4 (ave) mL/min
- 8.33 % Oxygen recovery
- 29.13 µmole Oxygen/g zeolite/cycle
- 270.30 µmole Oxygen/g zeolite/hr

# More Areas to be Discussed

- Design Limitations
- Calibration Issue
- Control Issue

# Future Work

- Explore ways to improve oxygen recovery and productivity
- Find out suitable bed dimensions and physical ratios that give better productivity
- Multiply bed number to meet production flow rate requirement
- Tailor a shorter cycle time

## Challenge:

How to make miniature oxygen concentrator via PSA that meets product purity and flow rate requirements feasible?