# Verde Valley Water Treatment

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CRKL Engineering
CENE 486 Capstone Team
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# Project Background

Dr. Paul Gremillion [1]

Dr. Terry Baxter [2]

Contaminants

- Arsenic (As): 1-2 mg/L
- Nitrate ($NO_3^-$): 25-40 mg/L

Sources of Contamination

- Both sources occur naturally
- As - agriculture & industrial activities
- $NO_3^-$ - fertilizers, animal & plant waste

Health Effects

- As - heightened cancer risk, pregnancy complications
- $NO_3^-$ - vascular collapse, Blue Baby Syndrome

Environmental Protection Agency Drinking Water Standards [3]

- As : 0.01mg/L
- $NO_3^-$ : 10 mg/L

# Literature Reviews

Figure 1: Activated Alumina 3/16” [4]

**Conventional**

Nitrate - Ion exchange with Chloride

Arsenic - Oxidation

**Sustainable**

Nitrate - Bio Film Reactor

Arsenic - Phytoremediation using Hyacinth roots

**Innovative**

Nitrate - Activated Alumina based ion exchange

Arsenic - ElectroChemical Arsenic Remediation

**Sustainable**

Nitrate - Permeable reactive barriers

Arsenic - Ceramic membrane filters with metal oxides

# Decision Matrix

Table 1. Decision matrix

| | | | | Nitrate | | | Arsenic | | | | Dual Treatment | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Criteria | Weights (%) | Ion Exchange: Chloride | Bio Film Reactor | Permeable Reactive Barrier | Oxidation | Electro Chemical | Phytoremediation Hyacinth Roots | Ceramic membrane filters | Ion Exchange: Titanium Oxide | Ion Exchange: Activated Alumina |
| Parameters | 1 | Low-Cost | 30 | 9 | 3 | 1 | 9 | 3 | 9 | 9 | 9 | 9 |
| | 2 | Low-Energy | 30 | 3 | 9 | 3 | 1 | 1 | 9 | 9 | 9 | 9 |
| | 3 | Feasibility | 20 | 9 | 1 | 1 | 3 | 1 | 3 | 1 | 9 | 9 |
| | 4 | System Life-Time | 15 | 3 | 3 | 9 | 9 | 9 | 3 | 3 | 3 | 9 |
| | 5 | Minimal by-product | 5 | 1 | 9 | 3 | 1 | 3 | 1 | 1 | 3 | 3 |
| | 6 | | | | | | | | | | | |
| | 7 | | | | | | | | | | | |
| | | | Raw score | 5.9 | 4.7 | 2.9 | 5 | 2.9 | 6.5 | 6.1 | 7.8 | 8.7 |
| | | | Ranking | 3 | 4 | 5 | 5 | 6 | 3 | 4 | 2 | 1 |

# Design Construction

Figure 2: Kyle and Robert at The Farm [5]

Figure 3: Lizzie and Camille at The Farm [5]

# Design Construction

Figure 4: Design before stain [5]

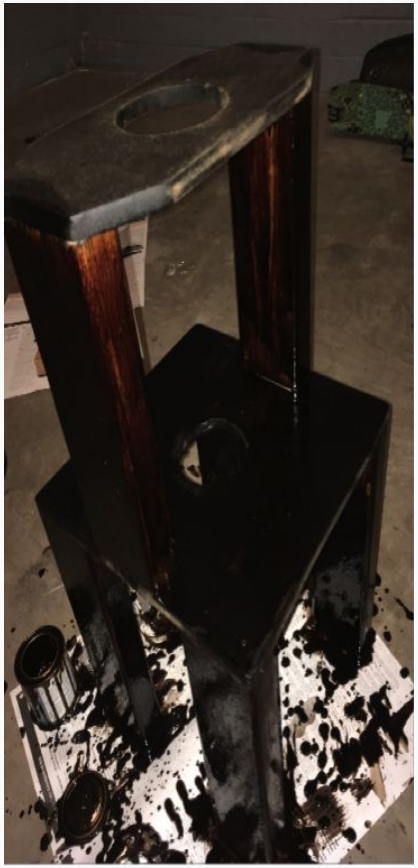

Figure 5: Design after stain [5]

Figure 6: Valve apparatus [5]

# Water Contamination

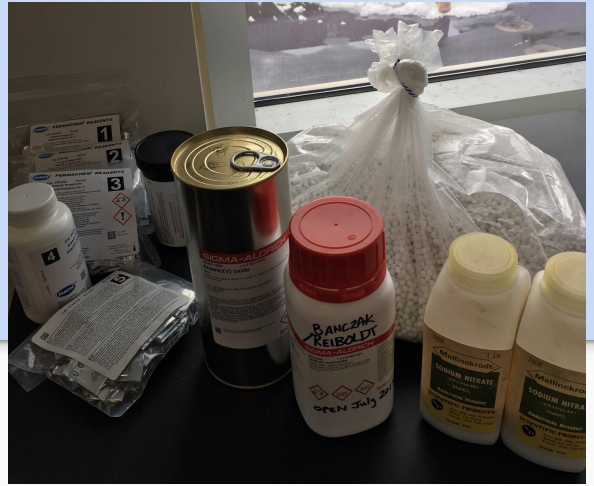


Figure 7: Water contamination chemicals [5]

Table 2: Water solutions created

| Solution | Amount (L) | Arsenic Pentoxide (mg) | Sodium Hydroxide (mg) | Sodium Nitrate (mg) |
|---|---|---|---|---|
| Combined | 8.50 | 19.56 | 51.00 | 407.83 |
| Arsenic | 2.50 | 5.75 | 15.00 | - |
| Nitrate | 1.50 | - | - | 71.97 |

# Water Testing

1. Stagnant batch tests using graduated cylinder
2. Trials
   a. 10 with mixed stock
   b. 5 with arsenic stock
   c. 4 with nitrate stock
3. Collected samples at 1, 5, 20, & 60 minutes
4. HACH test strips for arsenic tests
5. Used new activated alumina every 5 trials for solutions containing arsenic
6. Used new activated alumina each trial for nitrate solution
7. In-lab nitrate testing

Figure 8: Original testing design [5]

Figure 9: Batch testing design [5]

# Water Testing

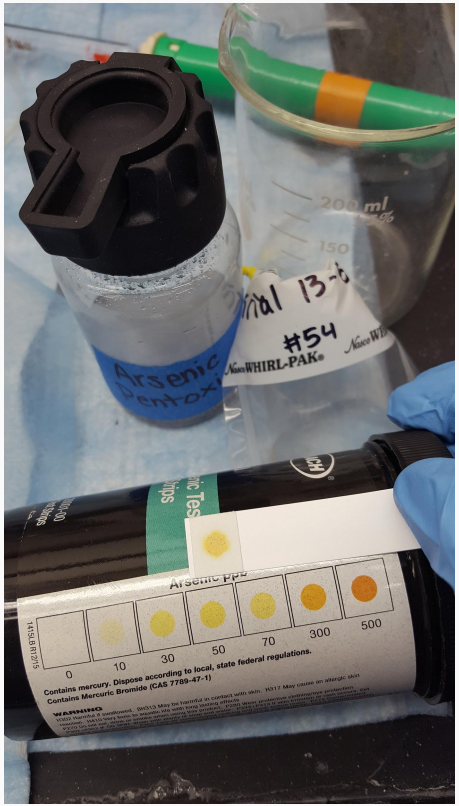


Figure 10: HACH Arsenic low range test kit [5]

Figure 11: HACH Nitrate method #8171 [5]

Figure 12: Samples for Dr. Ketterer at MSUD Lab [5]

# Arsenic Solution Results

Initial Arsenic Concentration: 1.7 mg/L  Arsenic Treatment Goal: 0.01 mg/L

Table 3. Arsenic solution results

| Arsenic Solution | | | | |
|---|---|---|---|---|
| | 1 minute | 5 minutes | 20 minutes | 60 minutes |
| Trial | Arsenic (mg/L) | Arsenic (mg/L) | Arsenic (mg/L) | Arsenic (mg/L) |
| 1 | 0.768 | 0.24 | 0.061 | 0.026 |
| 2 | 0.741 | 0.278 | 0.09 | 0.048 |
| 3 | 0.89 | 0.388 | 0.15 | 0.073 |
| 4 | 0.992 | 0.461 | 0.166 | 0.096 |
| 5 | 1.127 | 0.461 | 0.181 | 0.107 |
| Averages | 0.904 | 0.366 | 0.130 | 0.070 |
| Standard Dev. | 0.143 | 0.092 | 0.046 | 0.030 |

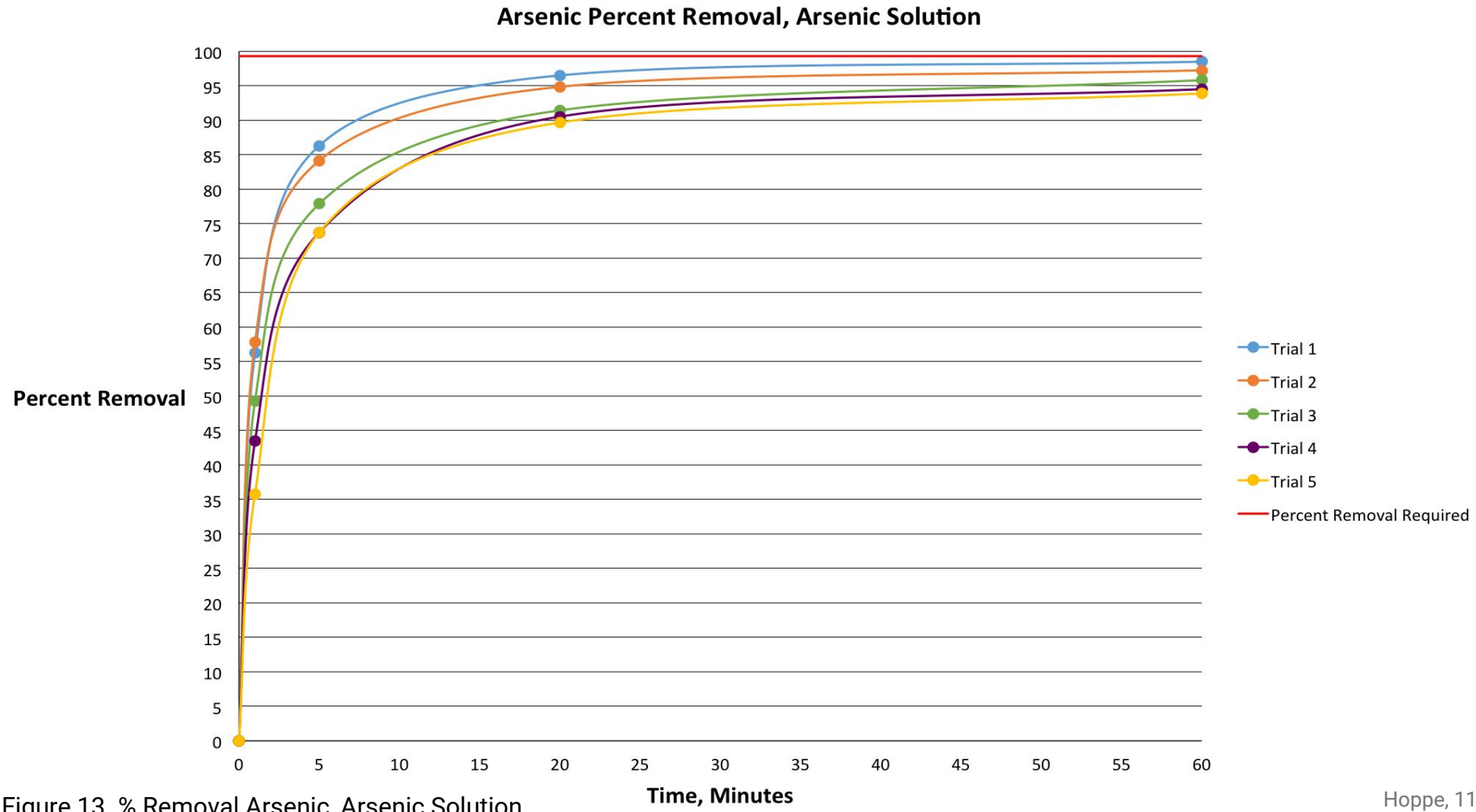


Figure 13. % Removal Arsenic, Arsenic Solution

# Nitrate Solution Results

Initial Nitrate Concentration: 35 mg/L

Nitrate Treatment Goal: 10 mg/L

Table 4. Nitrate solution results

| Nitrate Solution | | | | |
|---|---|---|---|---|
| | 1 minute | 5 minutes | 20 minutes | 60 minutes |
| Trial | Nitrate (mg/L) | Nitrate (mg/L) | Nitrate (mg/L) | Nitrate (mg/L) |
| 1 | 24.750 | 0.3 | 0.3 | 0.3 |
| 2 | 24.752 | 0.3 | 0.3 | 0.3 |
| 3 | 31.824 | 1.5 | 0.3 | 0.3 |
| 4 | 26.078 | 0.3 | 0.3 | 0.3 |
| Averages | 26.851 | 0.6 | 0.3 | 0.3 |
| Standard Dev. | 2.922 | 0.5 | 0 | 0 |

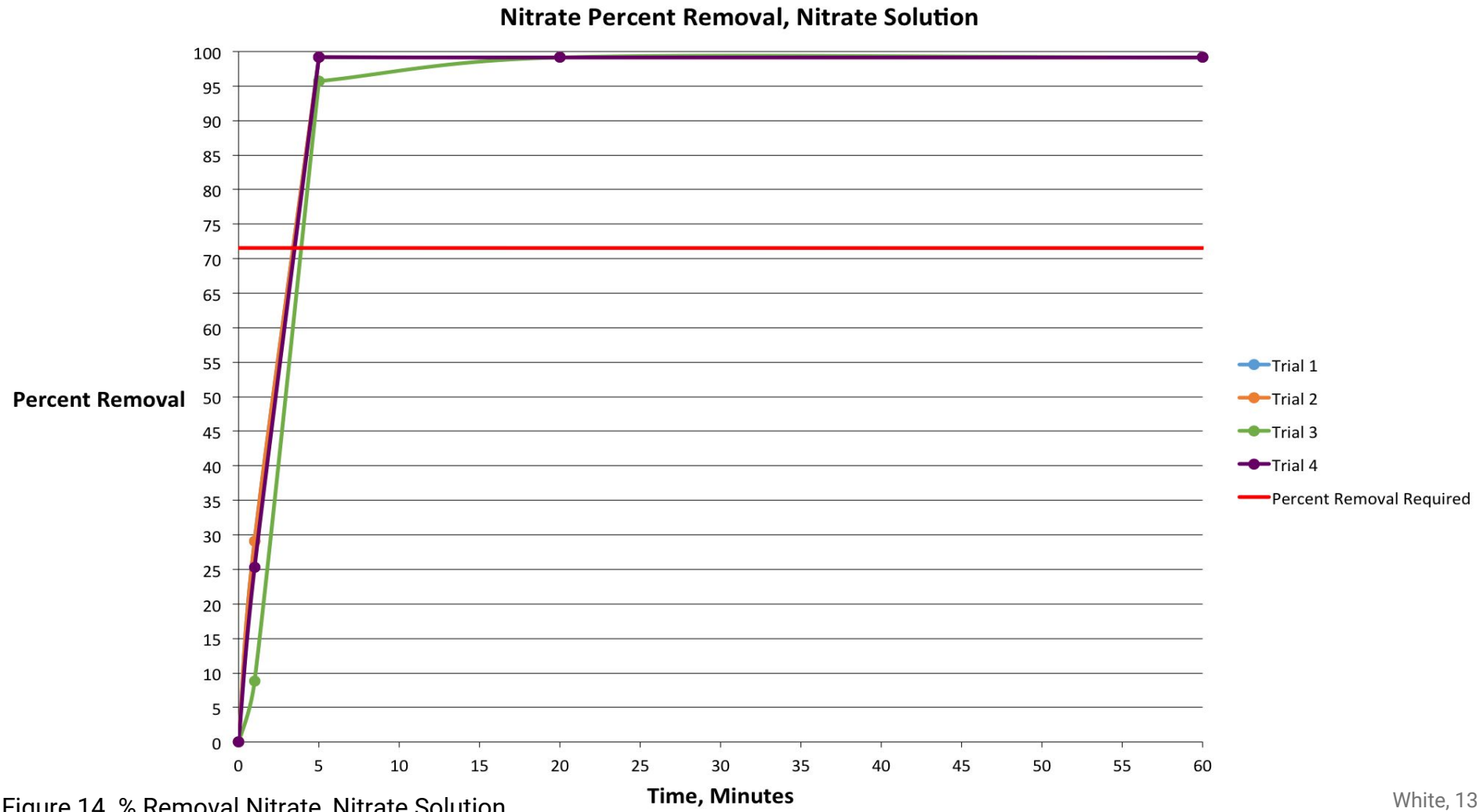


Figure 14. % Removal Nitrate, Nitrate Solution

# Combined Solution Results

Initial Arsenic Concentration: 1.5 mg/L
Initial Nitrate Concentration: 35 mg/L

Arsenic Treatment Goal: 0.01 mg/L
Nitrate Treatment Goal: 10 mg/L

Table 5. Combined solution results

| Arsenic and Nitrate Solution | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1 minute | | 5 minutes | | 20 minutes | | 60 minutes | |
| Trial | Arsenic (mg/L) | Nitrate (mg/L) | Arsenic (mg/L) | Nitrate (mg/L) | Arsenic (mg/L) | Nitrate (mg/L) | Arsenic (mg/L) | Nitrate (mg/L) |
| 1 | 0.584 | 8.84 | 0.124 | 0.30 | 0.038 | 0.30 | 0.011 | 0.30 |
| 2 | 0.625 | 15.47 | 0.153 | 0.30 | 0.057 | 0.30 | 0.024 | 0.30 |
| 3 | 0.472 | 0.30 | 0.158 | 7.07 | 0.071 | 33.60 | 0.043 | 0.30 |
| 4 | 0.693 | 4.86 | 0.296 | 0.30 | 0.116 | 0.30 | 0.063 | 0.30 |
| 5 | 0.846 | 10.17 | 0.307 | 0.30 | 0.132 | 0.30 | 0.082 | 0.30 |
| 6 | 0.584 | 19.01 | 0.164 | 15.03 | 0.045 | 35.80 | 0.012 | - |
| 7 | 0.462 | 11.05 | 0.18 | 0.30 | 0.062 | 0.30 | 0.037 | 0.30 |
| 8 | 0.649 | 26.08 | 0.226 | 0.30 | 0.086 | 0.30 | 0.052 | 13.70 |
| 9 | 0.634 | 23.87 | 0.234 | 22.10 | 0.111 | 0.30 | 0.069 | 11.50 |
| 10 | 0.339 | 11.93 | 0.105 | 0.30 | 0.056 | 0.30 | 0.047 | 5.75 |
| Averages | 0.589 | 13.16 | 0.195 | 4.63 | 0.077 | 7.18 | 0.044 | 3.64 |
| Standard Dev. | 0.133 | 7.67 | 0.065 | 7.42 | 0.031 | 13.77 | 0.023 | 5.10 |

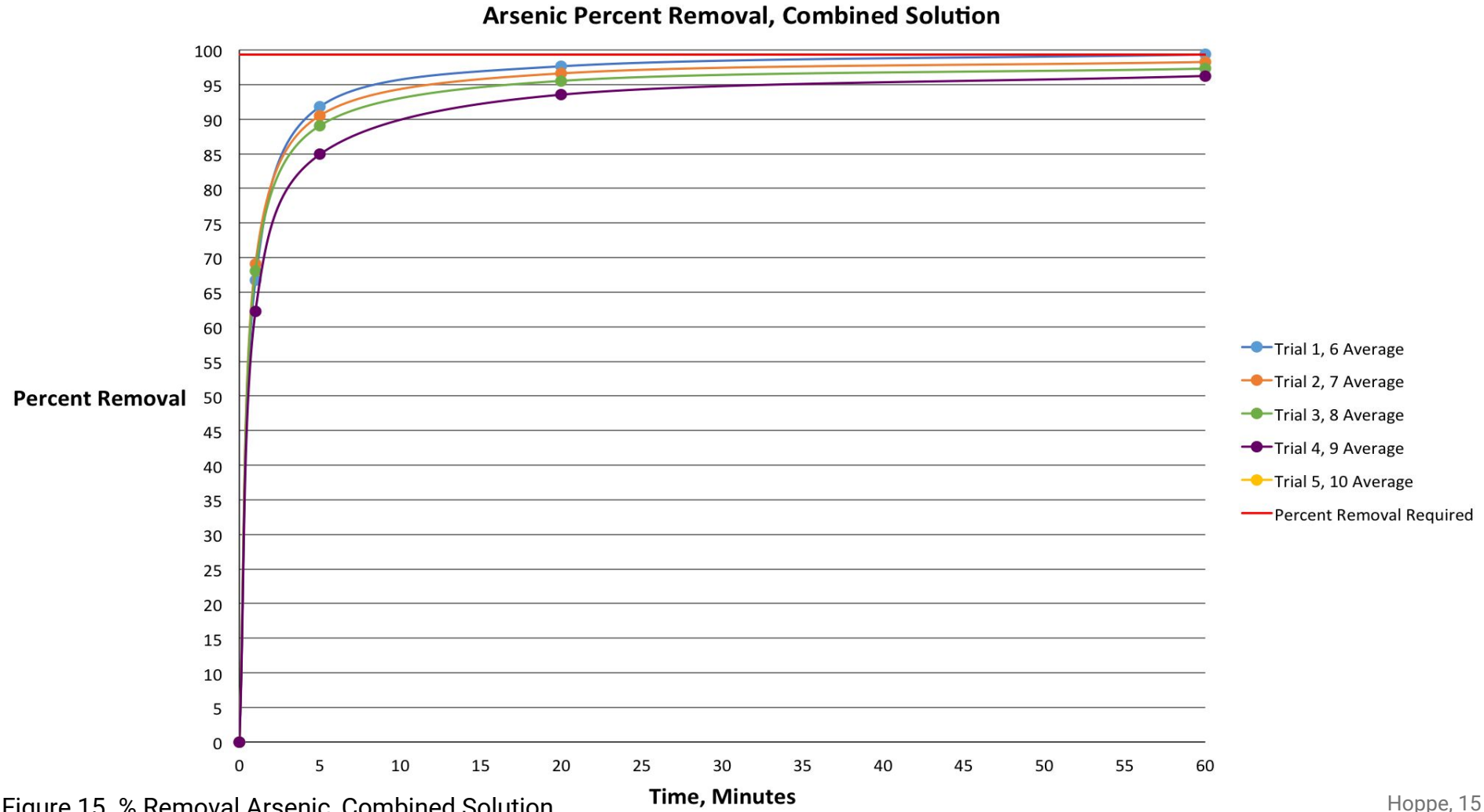


Figure 15. % Removal Arsenic, Combined Solution

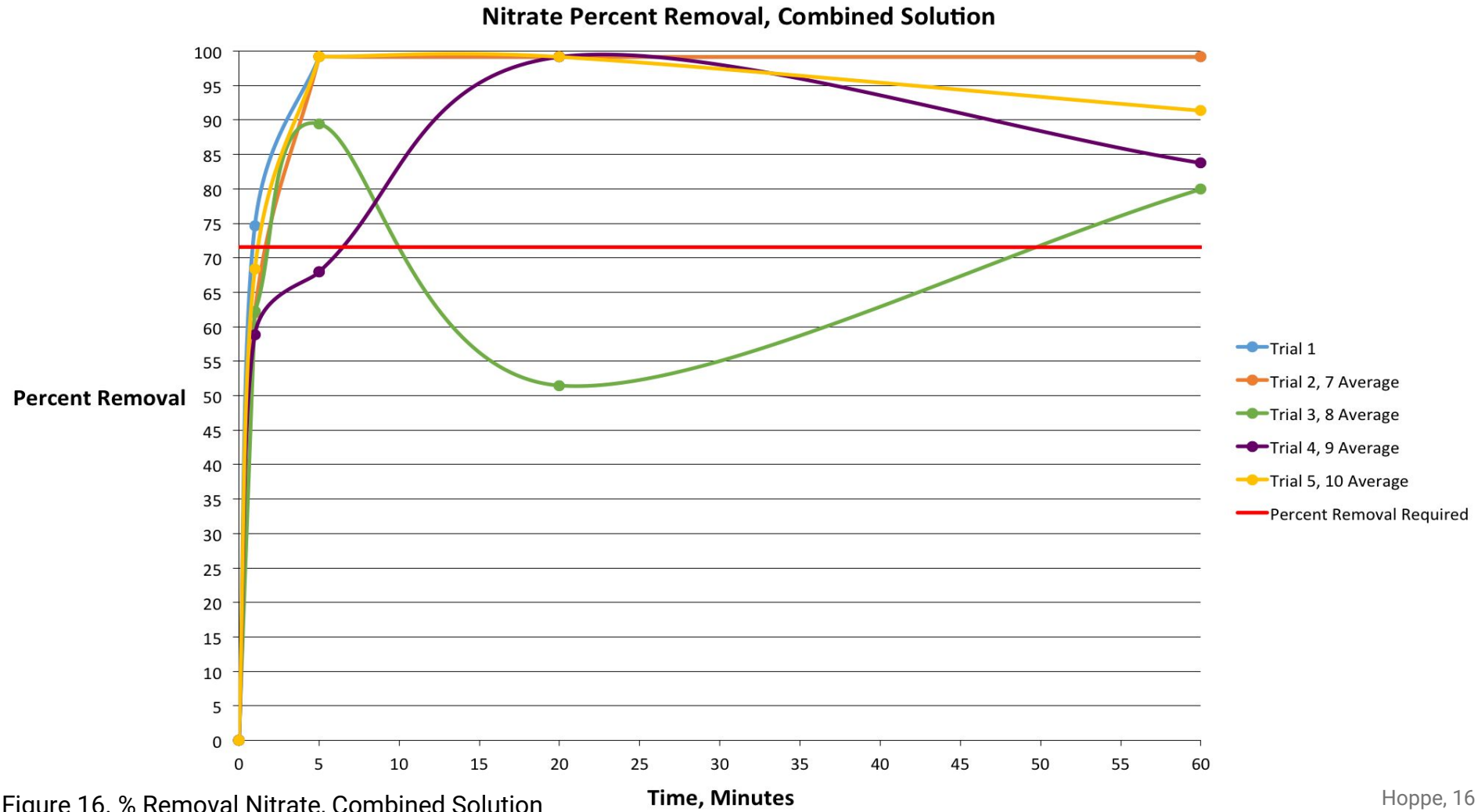


Figure 16. % Removal Nitrate, Combined Solution

# Recommendations

- Activated Alumina for Nitrate removal
- Multi-unit treatment system
- Further analysis
  - Activated Alumina isotherm


Figure 17: CRKL Engineering Team [5]

# Project Management

Table 6. Status schedule

| Task Name | Predicted End | Actual End |
|---|---|---|
| **4.0 Design Preparations** | | |
| *4.1 Acquire Lab Space* | 1/13/17 | 2/7/17 |
| *4.2 Lab Certifications* | 1/13/17 | 1/21/17 |
| *4.3 Acquire Lab Materials* | 2/2/17 | 2/13/17 |
| *4.4 Water Contamination* | 2/9/17 | 2/28/17 |
| **5.0 Design Development** | | |
| *5.1 Design Construction* | 2/23/17 | 3/5/17 |
| *5.2 Water Testing* | 2/28/17 | 3/21/17 |
| *5.2.1 Send Samples for Testing* | 3/3/17 | 3/10/17 |
| *5.3 Analyze Test Results* | 3/30/17 | 4/23/17 |
| *5.4 Final Presentation* | 4/27/17 | 4/27/17 |
| *5.5 Final Design Report & Website* | 5/5/17 | 5/5/17 |
| **6.0 Project Management** | | |
| *6.1 Team Meetings* | ongoing | ongoing |
| *6.2 Client Meetings* | ongoing | ongoing |
| *6.3 Technical Advisor Meetings* | ongoing | ongoing |

# Personnel Hours

Table 7. Personnel positions

| | |
|---|---|
| Senior Engineer | SENG |
| Engineer | ENG |
| Lab Technician | LAB |
| Engineering Intern | INT |
| Administrative Assistant | AA |

Table 8. Total hours

| Total Expected | Total Achieved |
|---|---|
| 708 | 530 |

Table 9. Hours by position

| Task | SENG | ENG | LAB | INT | AA |
|---|---|---|---|---|---|
| **Research** | 20 | 15 | 18 | 20 | 10 |
| **Lab Preparation** | 8 | 9 | 10 | 3 | 20 |
| **Water Contamination** | 10 | 9 | 7 | 10 | 4 |
| **Model Construction** | 10 | 26 | 0 | 8 | 7 |
| **Modeling** | 20 | 32 | 110 | 40 | 20 |
| **Results Analysis** | 40 | 26 | 0 | 0 | 18 |
| **Total** | 108 | 117 | 145 | 81 | 79 |
| **Projected** | 112 | 152 | 144 | 140 | 160 |

# Project Cost

Table 10. Total project costs based on actual hours

| Cost | Classification | Hours | Rate $/hr | Cost | Projected Cost |
|---|---|---|---|---|---|
| **Personnel** | SENG | 108 | $132 | $14,256 | $14,780 |
| | ENG | 117 | $69 | $8,073 | $10,490 |
| | LAB | 145 | $52 | $7,540 | $7,490 |
| | INT | 81 | $19 | $1,539 | $2,660 |
| | AA | 79 | $41 | $3,239 | $6,560 |
| | **Total personnel** | | | $32,647 | $41,980 |
| **Lab Work** | Materials | | $967 | $967 | $2,500 |
| | Lab Rental | 40 days | $100/day | $4,000 | $4,000 |
| | **Total Lab Work** | | | $4,967 | $6,500 |
| **Subcontract** | Analytical | | | $500 | $2,500 |
| **TOTAL** | | | | $38,114 | $50,980 |

# Cost of Implementation

Table 11: Total water consumption

| | |
|---|---|
| **Community Population** | 10,000 people |
| **Average Water Consumption** | 60 gpd per person |
| **Total Water Consumption** | 600,000 gpd |

Table 12: Total system cost

| | **Nitrate** | **Arsenic** | **Annual Totals** |
|---|---|---|---|
| **Activated Alumina Required (lbs)** | 11,455 | 455 | 11,910 |
| **Cost** | $16,955.00 | $675.00 | $35,260 |

# Acknowledgements

Special thanks…

Dr. Bridget Bero

Dr. Wilbert Odem

Dr. Terry Baxter

Gerjen Slim

# References


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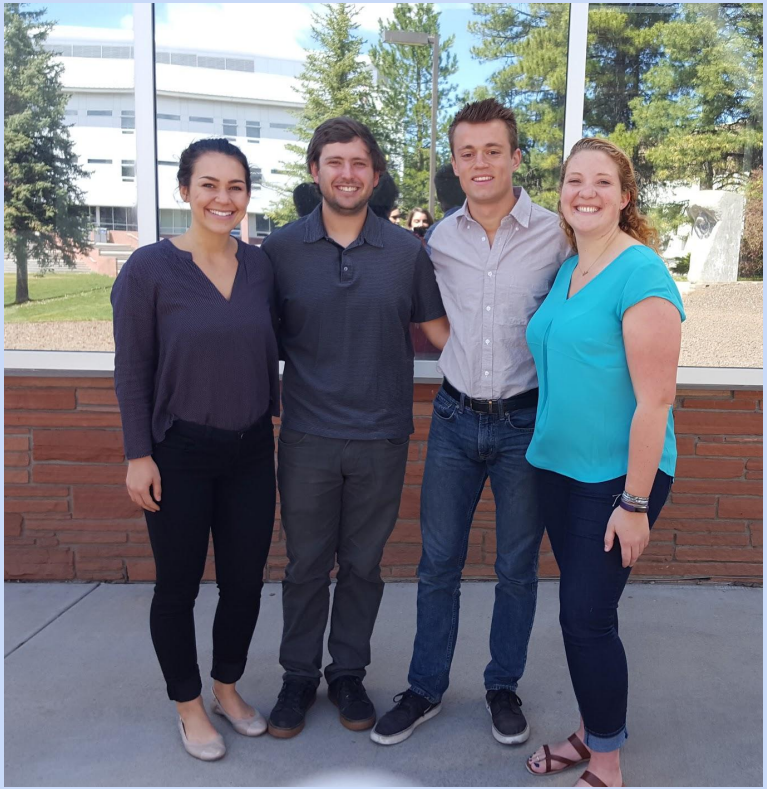


CRKL Engineering Team

# Supplementals - Water Contamination

**mixed solution**

using $NaNO_3^-$ : MW = 85 g/mol

$NO_3^-$ : MW = 62 g/mol

$\frac{62\ g/mol\ NO_3}{85\ g/mol\ NaNO_3} = 0.7294$

Target concentration: 35 mg/L $NO_3^-$

$NaNO_3^- = \frac{35\ mg/L\ NO_3^-}{0.7294} = 47.98\ mg/L\ NO_3^-$

using $NaNO_3^-$ to make a 35 mg/L $NO_3^-$ solution:

47.98 mg needed per L of solution

for 8.5 L of solution = 407.83 mg $NaNO_3^-$

**Mixed solution** (As and $NO_3^-$)

10 trials → 4 sample times of 150 mL

800 mL per trial (200 mL extra)

Solution must be 8 L ; make 8.5 L in case.

SM 18th Edition 1992 page 3-30

Stock As(V) solution:

- Dissolve 1.534g arsenic pentoxide, $As_2O_5$, in distilled water containing 4 g NaOH. Dilute to 1 L;
  1.00 mL = 1.00 mg As(V)

1.534g of $As_2O_5$ in 1 L = 1 g/L As(V)
to create solution with 1.5 mg/L As(V):

1.534 mg of $As_2O_5$ in 1 L = 1 mg/L As(V)
then:
2.301 mg of $As_2O_5$ in 1 L = 1.5 mg/L As(V)

for 8.5 L → (2.301 mg)(8.5)

**= 19.5585 mg $As_2O_5$**

for every 1.534 mg $As_2O_5$ → need 4 mg of NaOH

$\left(\frac{19.5585\ mg\ As_2O_5}{1.534\ mg\ As_2O_5}\right)\left(\frac{4\ mg\ NaOH}{}\right) =$ **51 mg NaOH**

# Supplementals - Water Contamination

**Nitrate solution**

(5 trials)(4 samples)(50 mL) = 1000 mL solution needed

*make 1.5 L of solution for some excess*

47.98 mg = 1 L

then:

1.5 L = 71.97 mg $NaNO_3$

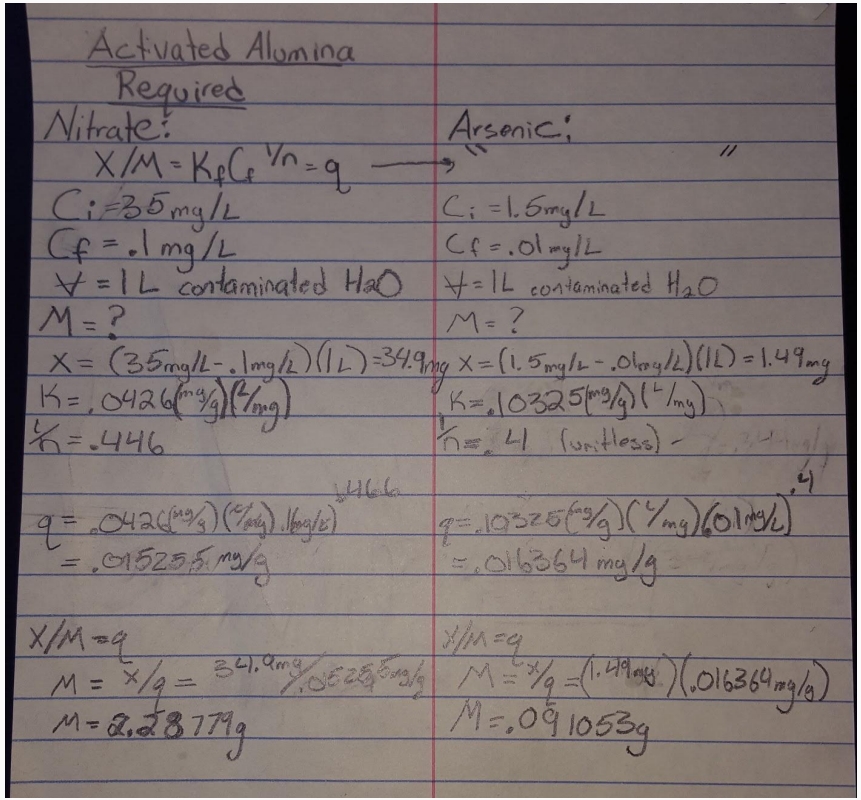
**Arsenic Solution**

(5 trials)(4 times)(110 mL) = 2100 mL solution ≈ 2.5 L solution

for 2 L → (2.301 mg $As_2O_5$)(2.5) = 5.752 mg $As_2O_5$

$\left(\frac{5.7525\ mg\ As_2O_5}{1.534\ mg\ As_2O_5}\right)\left(\frac{4\ mg}{NaOH}\right)$ = 15 mg NaOH

# Supplementals: Pounds needed for treatment



Activated Alumina

Required

Nitrate:

$X/M = K_f C_f^{1/n} = q$

$C_i = 35\ mg/L$

$C_f = .1\ mg/L$

$V = 1L$ contaminated $H_2O$

$M = ?$

$X = (35\ mg/L - .1\ mg/L)(1L) = 34.9\ mg$

$K = .0426\ (mg/g)(L/mg)$

$1/n = .446$

$q = .0426(.1)^{.446}$

$= .015255\ mg/g$

$X/M = q$

$M = X/q = 34.9\ mg / .015255\ mg/g$

$M = 2.28779\ g$

Arsenic:

$C_i = 1.5\ mg/L$

$C_f = .01\ mg/L$

$V = 1L$ contaminated $H_2O$

$M = ?$

$X = (1.5\ mg/L - .01\ mg/L)(1L) = 1.49\ mg$

$K = .10325\ (mg/g)(L/mg)$

$1/n = .41$ (unitless)

$q = .10325(.01)^{.41}$

$= .016364\ mg/g$

$X/M = q$

$M = X/q = (1.49\ mg)(.016364\ mg/g)$

$M = .091053\ g$

# Supplementals: Cost of Implementation

- Average Arizona resident uses 100 gallons of water per day (gpd) [9]
  - Reduced average to 60 gpd
- Community of 10,000 people requires 600,000 gpd
- Assuming there is a pre-existing drinking water treatment plant
- Arsenic removal: 455.93 lbs of activated alumina at $674.77
- Nitrate removal: 11,455.52 lbs of activated alumina at $16,954.17
- Annual cost of $35,257.88
  - Purchase twice the required amount so the system can be run and material can be regenerated simultaneously