# PILOT SCALE STUDY OF POLYMER ENHANCED ULTRAFILTRATION [PEUF] FOR ARSENIC REMOVAL

Daniel Gallo[a], Edgar Acosta[a], John F. Scamehorn[a] and David A. Sabatini[b*]

[a] Chemical Engineering and Materials Science
[b] Civil Engineering and Environmental Science
The Institute for Applied Surfactant Research
The University of Oklahoma

* Contact Information: sabatini@ou.edu

# Arsenic Rule

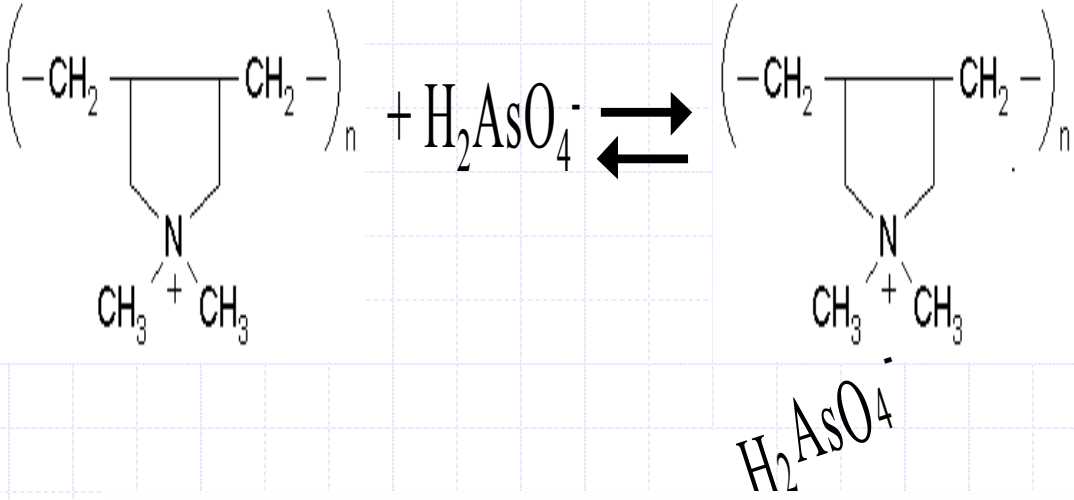
- ✓ **The US Environmental Protection Agency (EPA) published the final AR in 2001 which enforces a Maximum Concentration Limit (MCL) of 10 ppb.**

- ✓ **It is expected that approximately 4,000 systems will need to install new technology to comply with the 10 ppb (MCL) standard by January 23, 2006.**

- ✓**A compliance cost of $1.47 billion per year has been estimated.**

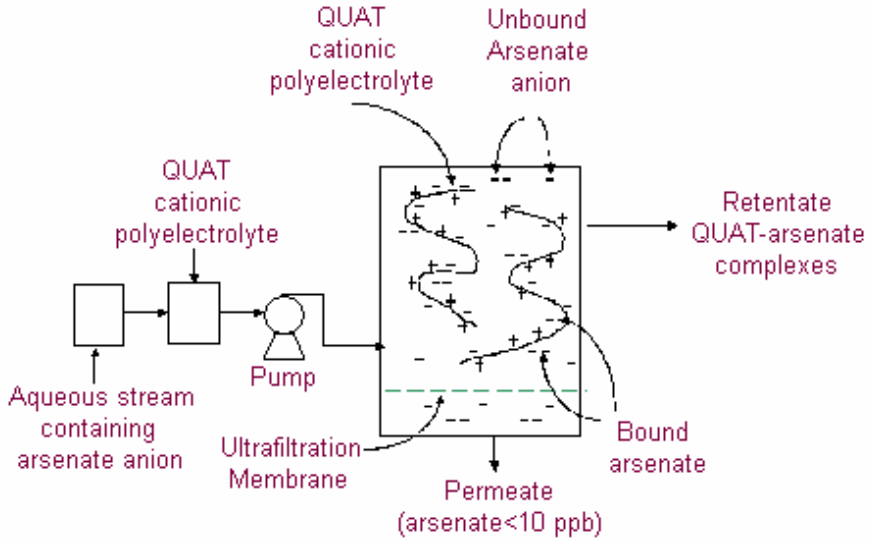
# Polyelectrolyte Enhanced Ultrafiltration (PEUF) for Arsenic Removal

Polymer: diallyldimethyl ammonium chloride (QUAT)




- Dissolved arsenic passes through UF membrane (10,000 Da)
- Arsenic / polyelectrolyte (QUAT) complex is larger (240,000 Da) than UF
- Arsenic / Quat complex is retained

$$\text{Rejection}(\%) = \left(1 - \frac{[\text{Arsenic}]_{per}}{[\text{Arsenic}]_{ret}}\right) \times 100$$



# System description

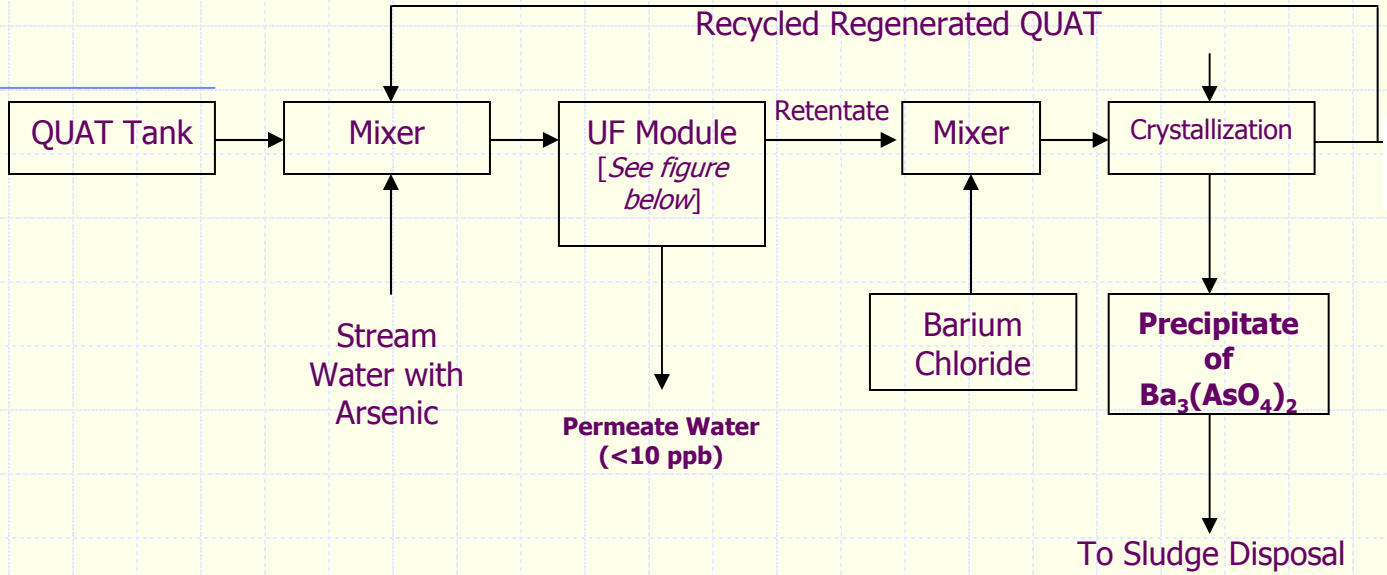
## Chemicals

- QUAT-Poly(diallydimethyl ammonium chloride), 240,000 Da
- Sodium arsenate

## Equipment

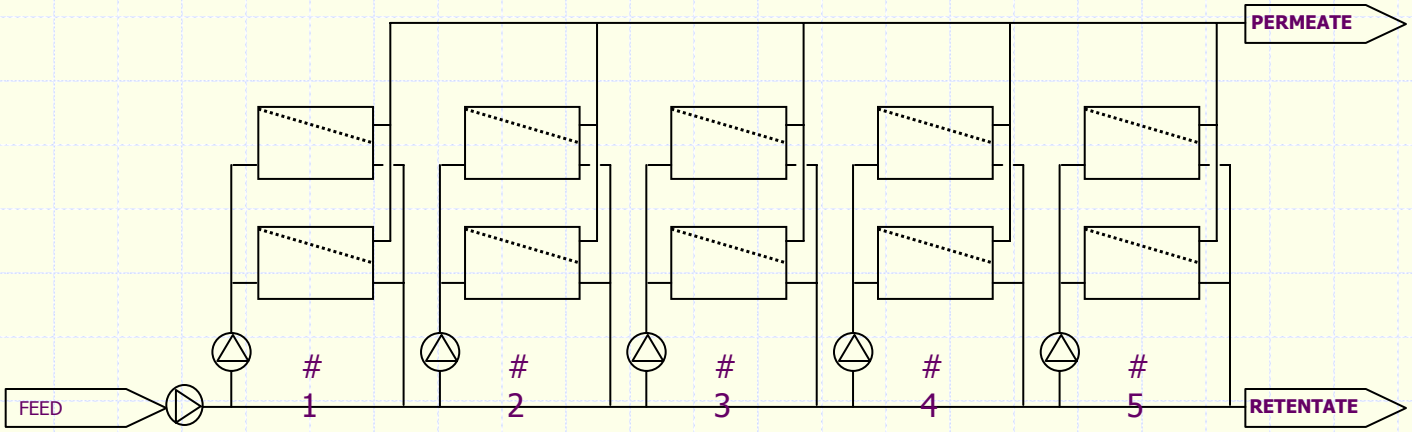
- Polyethersulfone ultrafiltration membrane with the following specifications: (Osmonics)
  - Molecular weight cut-off (MWCO): 10,000 Da
  - Recommended pH range: 2.0 – 11.5
  - Active Area: 90 $ft^2$ (8.36 $m^2$)
- Varian SpectrAA-30 coupled with VGA-77
- Dionex 500 ion chromatograph - sulfate determinations

# OVERALL FLOW DIAGRAM OF PEUF PROCESS

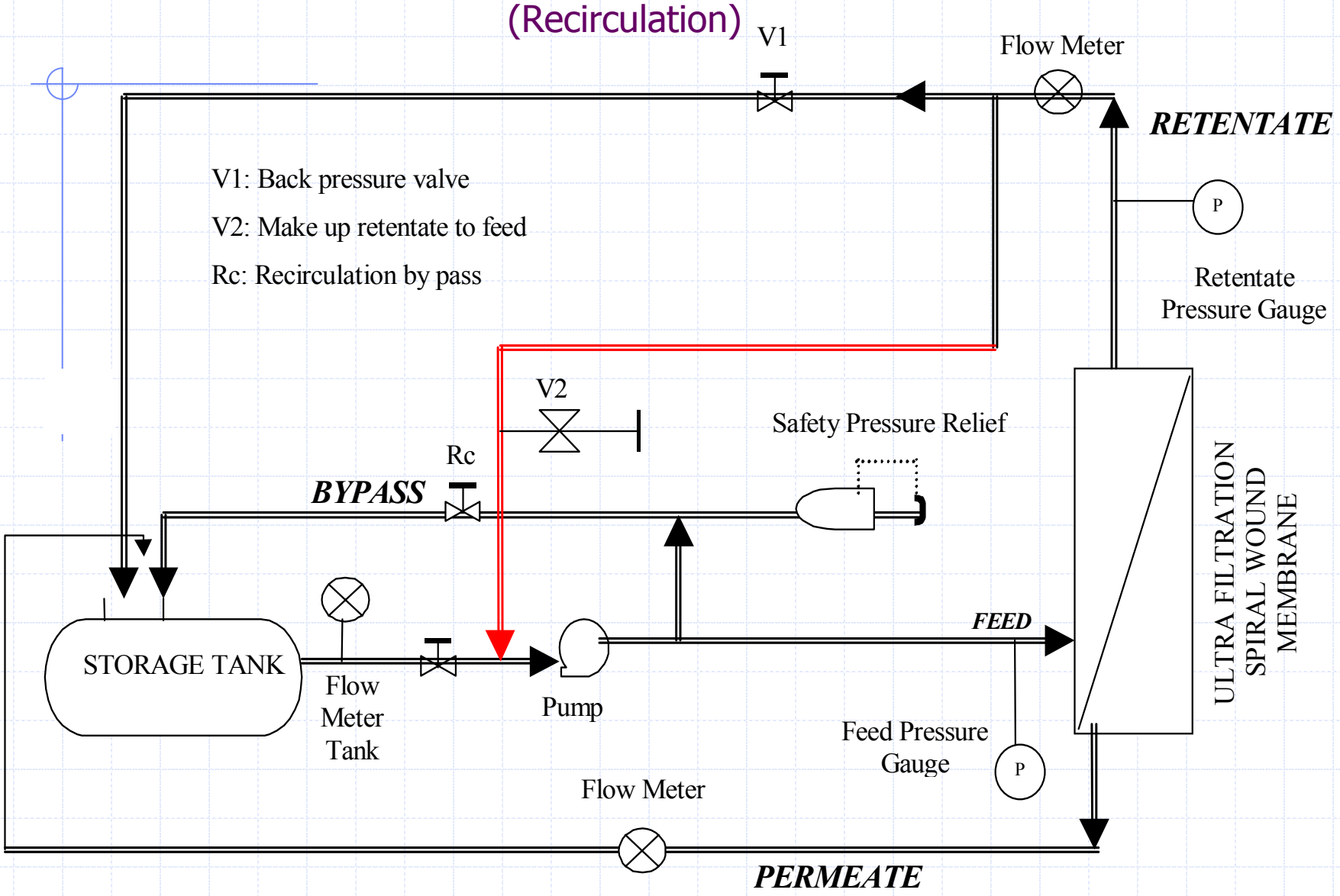



ULTRAFILTRATION MODULE

(staged if necessary to meet treatment goal)



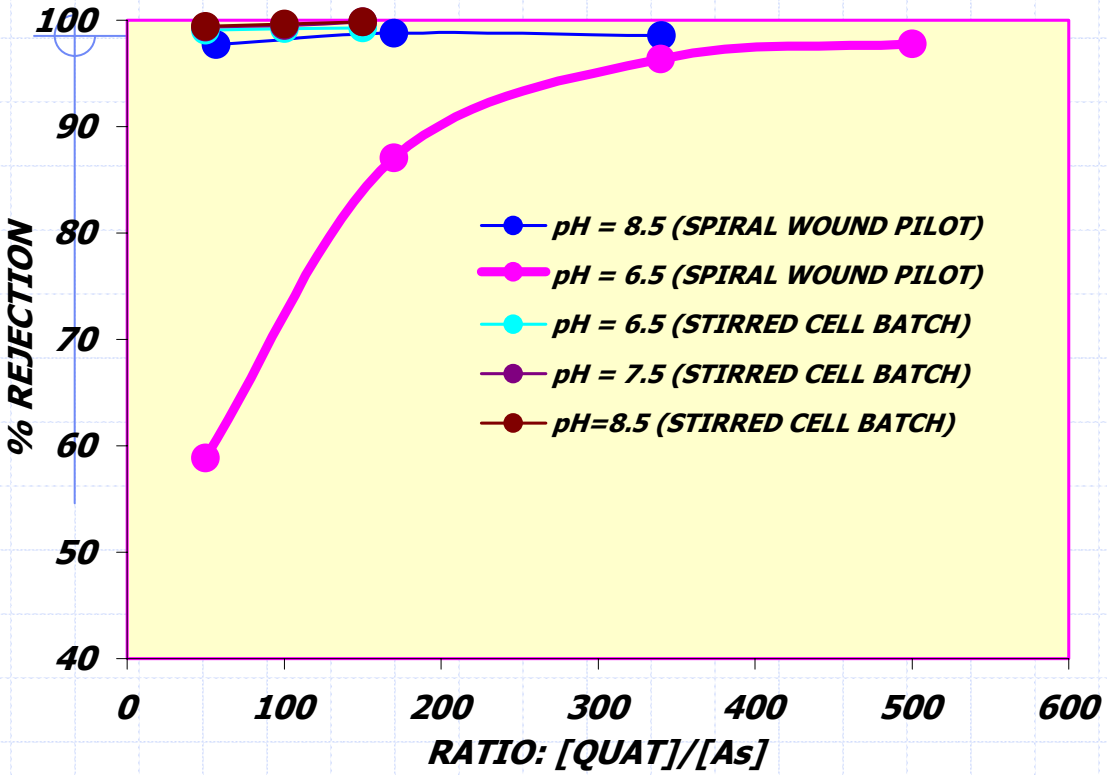
# MEMBRANE PILOT SCALE APPARATUS




Daniel Gallo
ULTRAFILTRATION UNIT
PUMP
TANK

# STIRRED CELL VERSUS CONTINUOS FLOW

## I. Influence of pH on Arsenic Removal




$[A]_{initial}$=100 ppb
Pressure feed= 65 psi

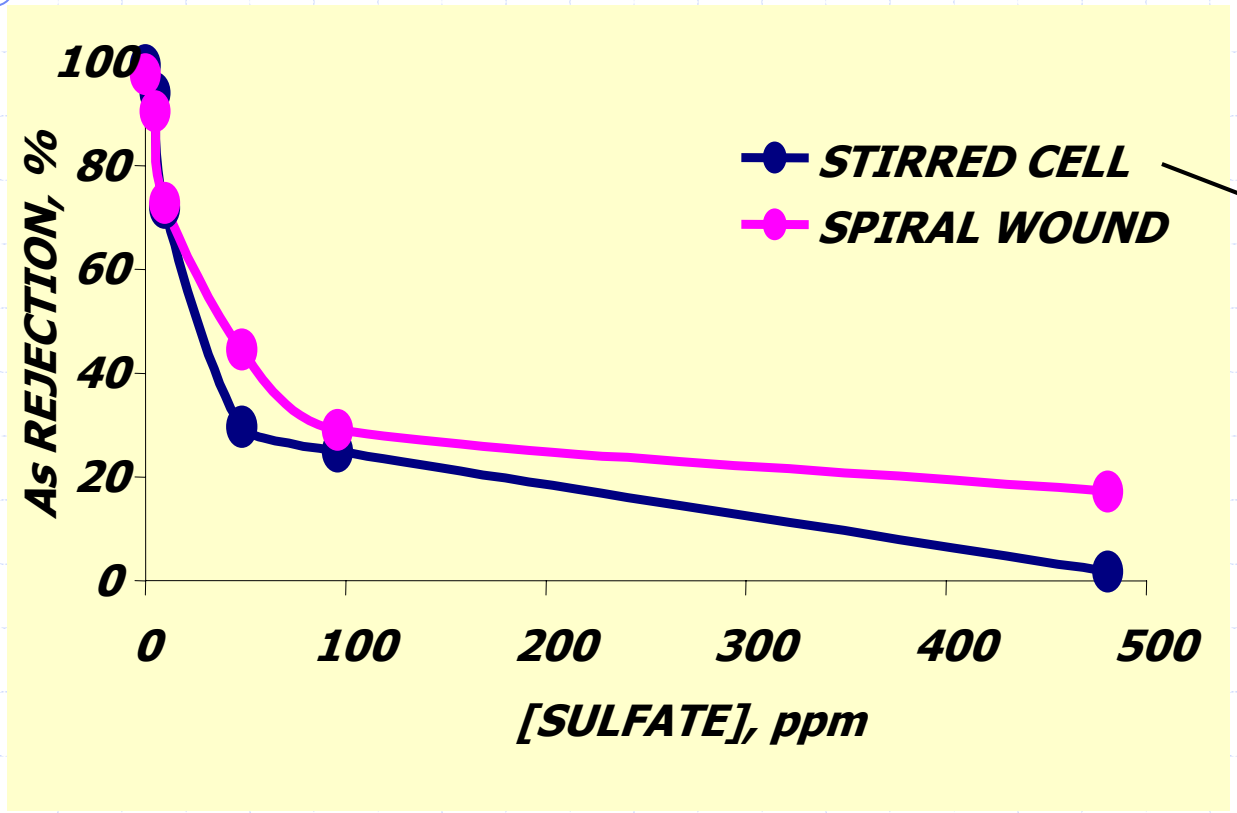
- Much better complexation at pH 8.5!

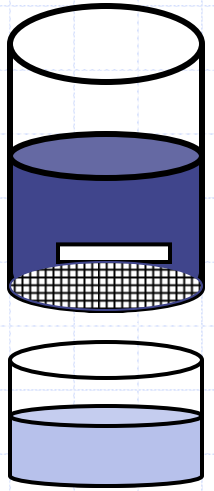
Molar arsenate distribution

| pH | $H_2AsO_4^-$ | $HAsO_4^=$ |
|---|---|---|
| 6.5 | 75 | 25 |
| 8.5 | 4 | 96 |

# STIRRED CELL VERSUS CONTINUOS FLOW(Cont.)

## II. Influence of Sulfate Ion Concentration on Arsenic Removal



Conditions:

[Arsenic]initial=100 ppb

Ratio:[QUAT]/[As]=100

pH = 7.5

***Impact of sulfate**

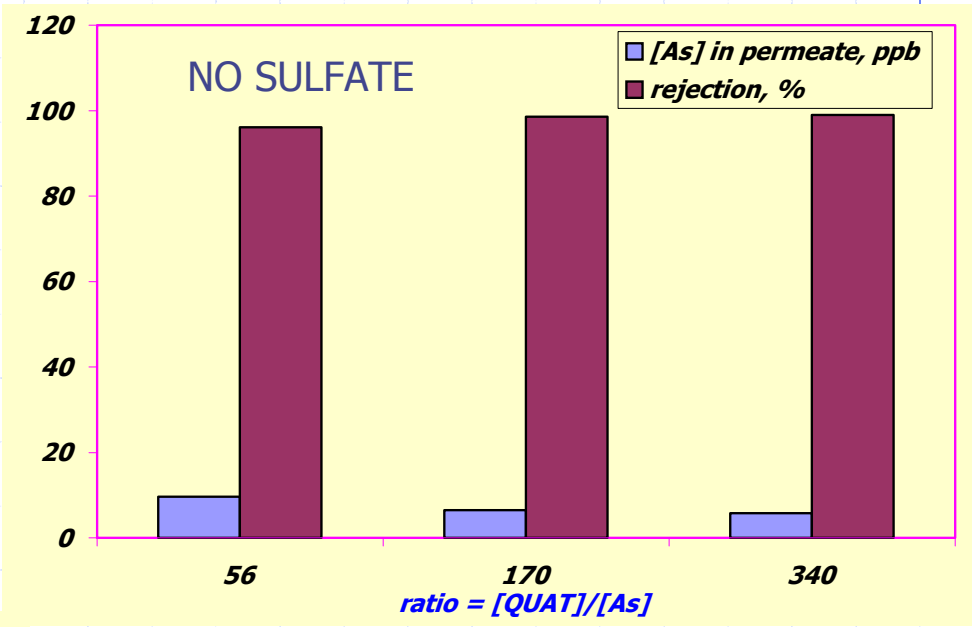
***Scale-up**

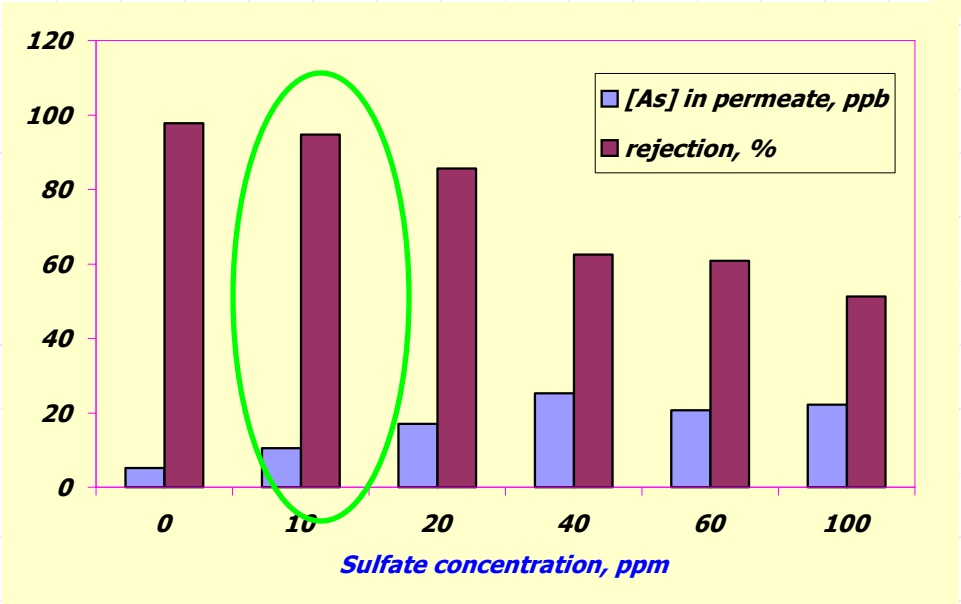
# PREFERRED CONDITIONS FOR ARSENIC REMOVAL

pH = 8.5

[Arsenic]$_{initial}$=50 ppb

NO SULFATE ION




**pH = 8.5**

**[Arsenic]$_{initial}$=50 ppb**

**Ratio: [QUAT]/[As]=500**

**[SULFATE]=10 ppm**

Presence of sulfate requires an order of magnitude increase in [QUAT]/[As] ratio to achieve [As] = 10 ppb

# OPERATIONAL PERFORMANCE

pH = 8.5

Arsenic = 50 ppb

Ratio: [QUAT]/[As]=500

$QUAT_{feed}$ = 54 ppm

$QUAT_{permeate}$ < 0.2 ppm

[SULFATE]=10 ppm

→ **Crossflow: 1.2-1.3 gpm  Flux: 77- 81 Lmh  Percent waste: 3-5%**

**Permeate flow: 2.8 gpm  % Recovery: 97  Feed press. : 67 psi**

Example Run

| TIME | FLOW (GPM) | | | | ARSENIC CONCENTRATION (ppb) | | | REJECTION | FLUX | RECOVERY | WASTE |
|---|---|---|---|---|---|---|---|---|---|---|---|
| (minutes) | TANK (well) | RETENTATE | PERMEATE | FEED | FEED | RETENTATE | PERMEATE | % | (Lmh) | % | % |
| 30 | 2.93 | 1.2 | 2.8 | 4.1 | 59.2 | 211.3 | 9.9 | 95.3 | 76.9 | 96.6 | 3.4 |
| 50 | 2.95 | 1.3 | 2.8 | 4.1 | 57.7 | 201.9 | 9.6 | 95.3 | 76.6 | 95.6 | 4.4 |
| 70 | 2.96 | 1.2 | 2.9 | 4.0 | 50.0 | 189.1 | 9.9 | 94.8 | 77.4 | 96.3 | 3.7 |
| AVERAGE | 2.9 | 1.2 | 2.8 | 4.1 | 55.7 | 200.7 | 9.8 | 95.1 | 77.0 | 96.2 | 3.8 |

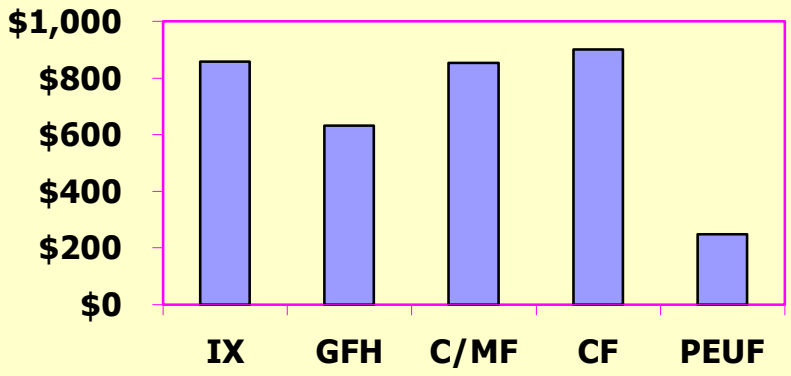
- **High Flux - 77 Lmh**
- **High Water Recovery – over 96%**
- **Crossflow of 1.2 to 1.5 gpm**
- **[As]perm < 10 ppb**

$$\text{Permeate Flux} = \frac{\text{Permeate Flow Rate}}{\text{Effective Membrane Area}}$$

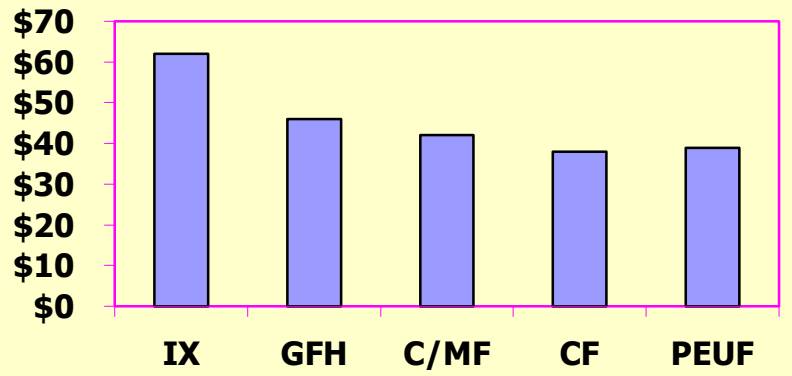
# COMPARATIVE STUDY OF TECHNOLOGIES FOR TREATING ARSENIC-IMPACTED GROUNDWATER IN NORMAN, OK

*[As (V)= 50 ppb; Sulfate = 9.5 ppm, flow=161 gpm]*

**CAPITAL, thousands $**

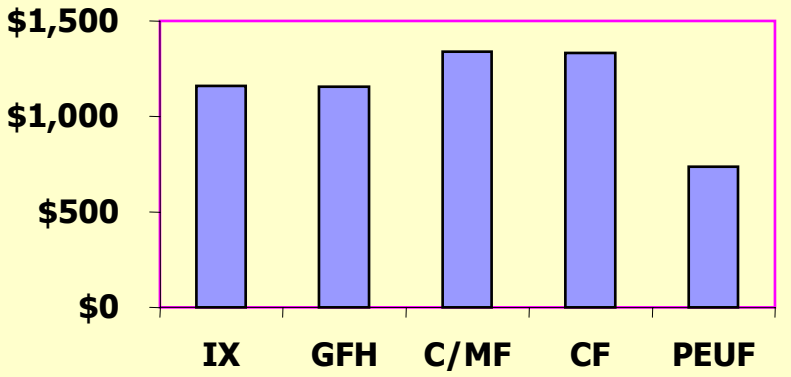



**ANNUAL O&M, thousands $**



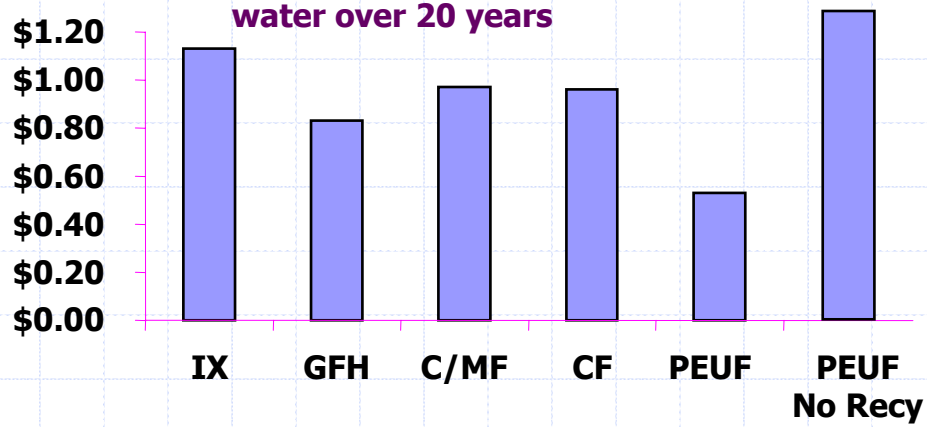

**TOTAL PRESENT WORTH, thousands $**

**Based on a 6% interest rate for 20 years**




**TOTAL UNIT COST, $/1,000**

**Based on average volume of treated water over 20 years**



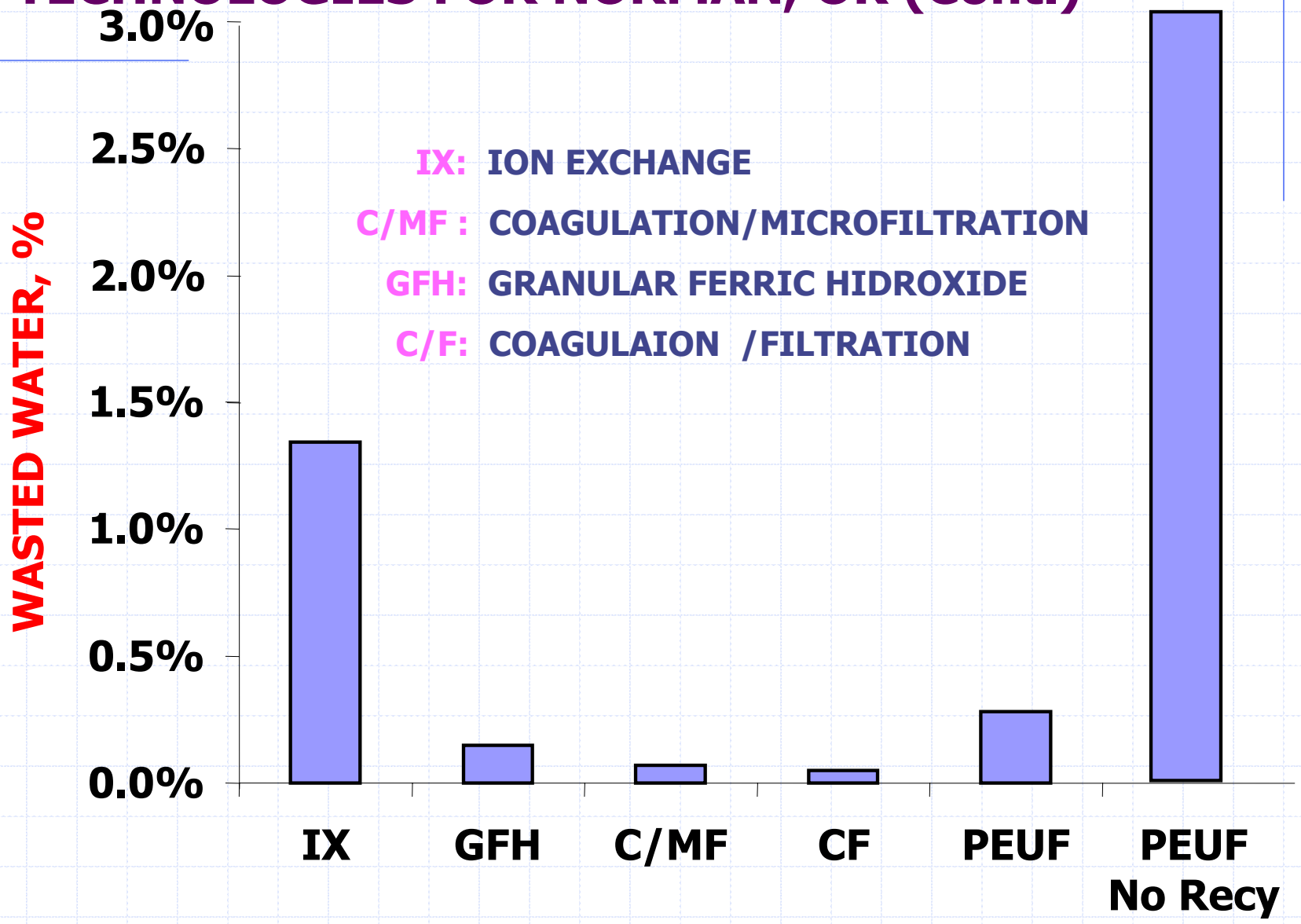

**IX:** ION EXCHANGE

**GFH:** GRANULAR FERRIC HYDROXIDE

**C/MF :** COAGULATION/MICROFILTRATION

**C/F :** COAGULAION /FILTRATION

# WATER WASTED FOR COMPARATIVE TECHNOLOGIES FOR NORMAN, OK (Cont.)



# Performance of PEUF

- Higher than 95% removal with QUAT/As ratios ~ 50 for arsenate @ pH 7.5 -8.5, without sulfate (ratio increased to 500 for 10 ppm of sulfate
- PEUF using QUAT achieved $[As]_{perm}$ < 10 ppb for $[As]_{inlet}$ concentrations up to 50 ppb and sulfate concentrations up to 10 ppm
- The economic evaluation for the City of Norman shows PEUF to be very competitive with the technologies evaluated, having the lowest TOTAL UNIT COST of $0.53/1,000 gal.