Removal of Hydrogen Sulfide from Groundwater by Granular Activated Carbon

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Co-authors and Acknowledgements

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  - Jay A. Kleinheinz, Duncan S. Lee – City of Huntington Beach
  - C. Bryan Trussell, David R. Hokanson – Trussell Technologies
- Acknowledgements
  - Steve Styles, Chris Cassotta, Derek Smith – City of Huntington Beach

Introduction

- Project locations: City of Huntington Beach's three potable wells
  - Well 3
  - Well 6
  - Well 9
- Design Capacity: 3,000 to 3,500 GPM each
- Current treatment
  - Chlorination (Free Cl_2 with gaseous Cl_2)
  - Fluoridation (HF)

Project Objective

- Utilize the groundwater to maximize the local water resources in the current drought situations
  - Historically the wells haven't been run at their full speed (50% to 60%)
  - Water quality concerns at the design production rates
    - Color (NOM): <5 CU → up to 15 CU
    - H_2S: non-detect → up to 0.2 mg/L
  - Addition of treatment facilities has been considered
    - Granular activated carbon (GAC)
    - Chlorine-bisulfite-chlorine
    - Ozone
  - GAC-based treatment has already been selected for one of the wells
    - Being considered at the other wells

Pilot Study Objectives

- GAC-based treatment has been tested by the City of Huntington Beach and a full-scale demo filter has been installed and used at Well 9 since 2010
  - The demo filter has a design capacity of 250 gpm
  - Coconut shell-based media
  - No backwash
- A series of pilot studies have been carried out
  - To evaluate the feasibility of the GAC-based treatment
  - To identify H_2S removal mechanisms
  - To ensure no odor or other unexpected water quality issues in the distribution system
  - To determine full-scale design parameters

History of On-site Pilot Studies

- 2006: Initial pilot study (up to 30 gpm) at Well 9
- 2009: Demo GAC filter vessel (250 gpm, sidestream) at Well 9
- 2014: Demo GAC filter monitoring (with chlorine) at Well 9 (Up to 350 gpm)
- 2014: Small pilot GAC at Well 9 (0.25 gpm)
- 2014: Demo GAC filter monitoring (without chlorine) at Well 9 (Up to 400 gpm)
- 2014-2015: Small pilot GAC at Wells 6 and 3 (Up to 0.6 gpm, reduced filter bed depth)
- 2015: Demo GAC filter monitoring (reduced filter bed depth) at Well 9 (ongoing)
- 2015: Small pilot GAC and non-GAC at Well 9 (Up to 0.6 gpm)

NOTE: Full-scale filters are being designed for Well 9

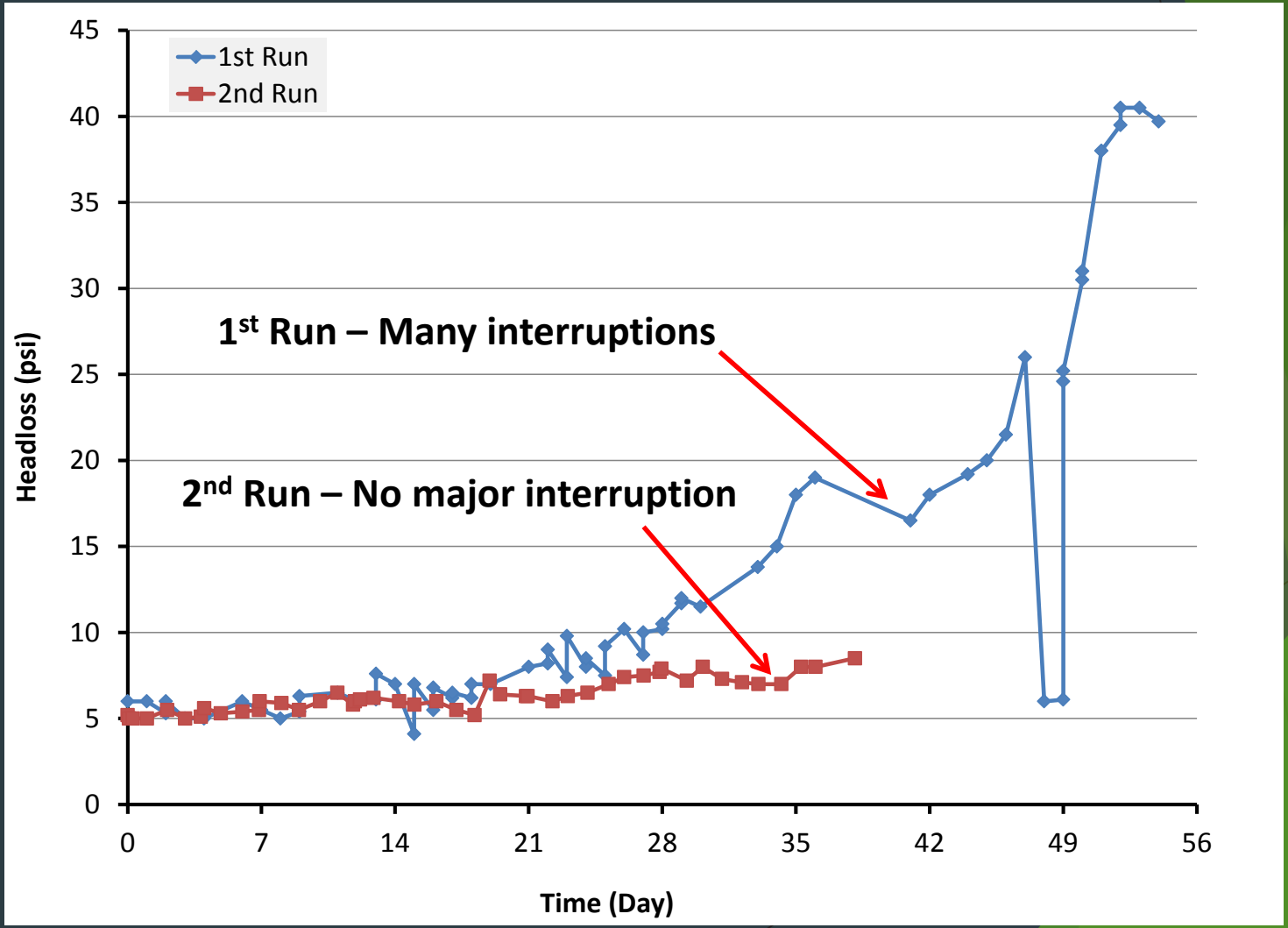
General Methodologies

- Pilot filters: Two scales
  - Demo GAC filter at Well 9 (250 to 400 gpm)
    - 10’ diameter
    - Surface loading rate: 3.5 to 5.6 gpm/ft^2
  - Pilot filtration skid (0.25 to 0.6 gpm)
    - Five 2’ filter columns (3” ID clear PVC), in series or in parallel
    - Surface loading rate: 5.1 to 12.8 gpm/ft^2
    - GAC media and non-GAC media
- Study periods
  - 4 to 8 weeks each
- Water quality parameters monitored
  - H_2S, color
  - pH, DO, ORP, TDS, temperature, turbidity, nitrate, odor, HPC, TOC
    - A flow cell was used to measure DO and ORP accurately

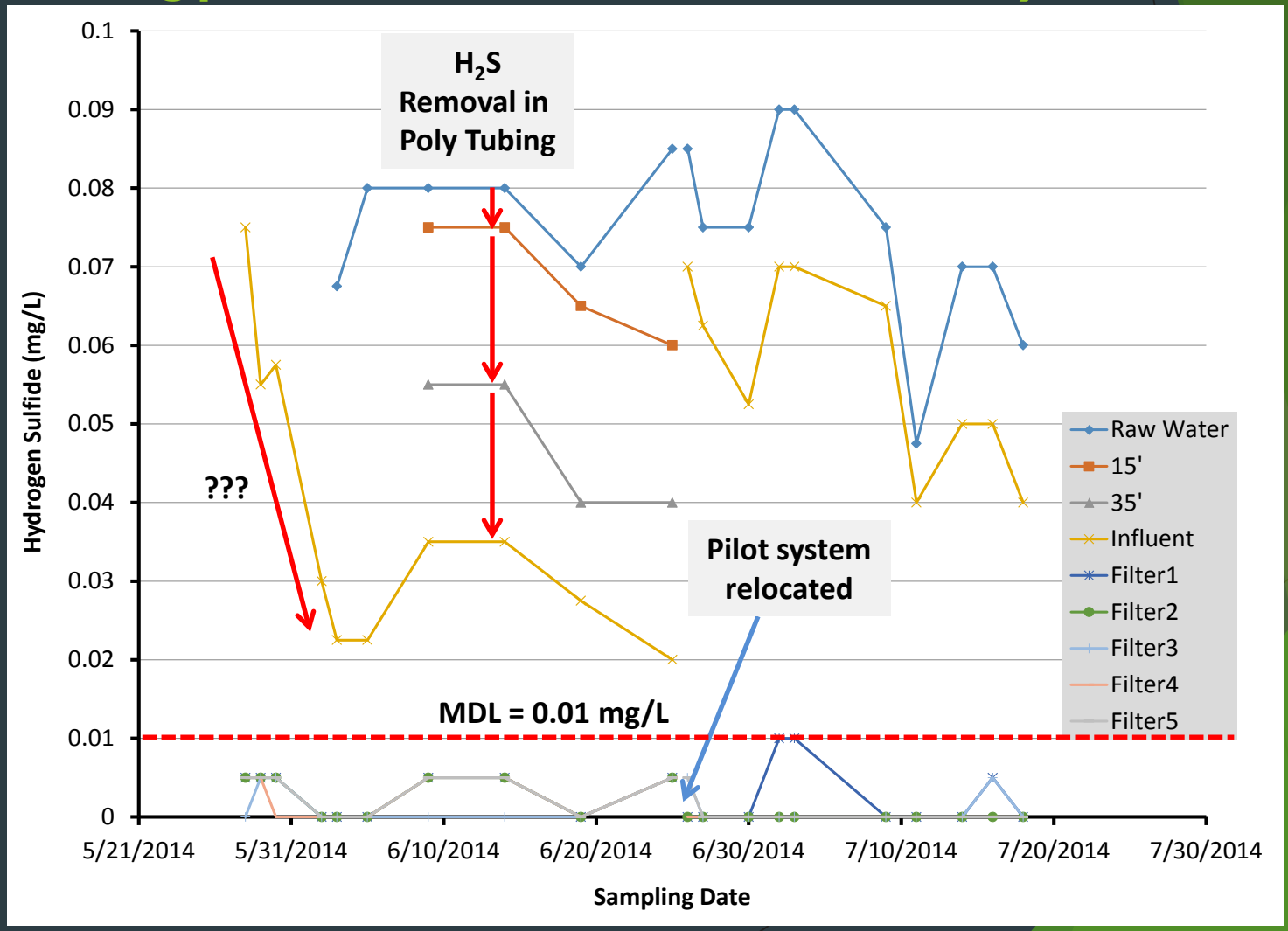
Coconut Shell GAC Media Specifications

- Mesh size: 12 x 30
- NSF 61 certified
- Carbon tetrachloride #: 60%
- Iodine #: 1,100 min
- Ash, weight %: 3 max
- Hardness %: 98 min
- Moisture as packed wt%: 3 max
- Apparent density g/cc: 0.45-0.52

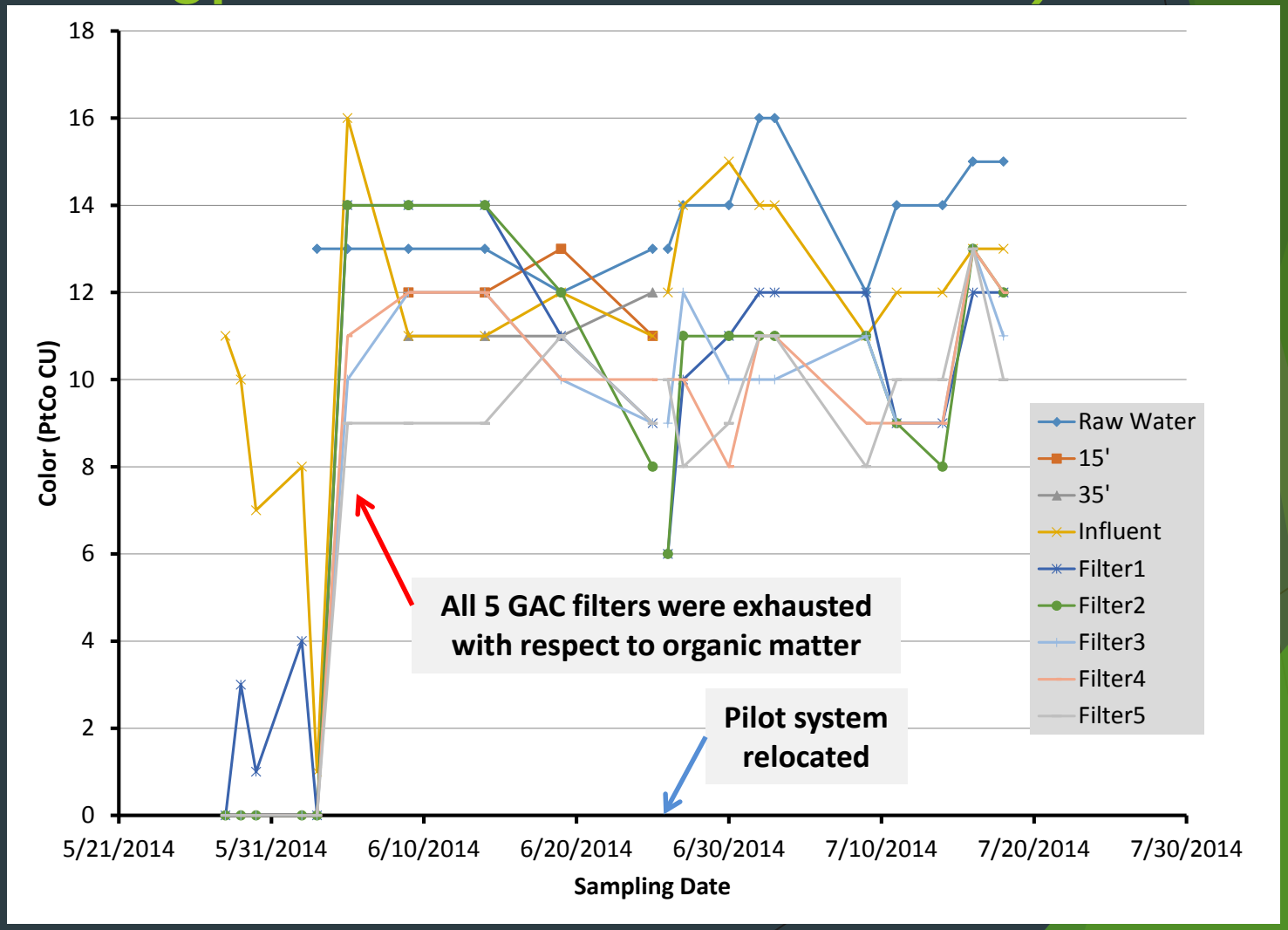
Head Loss in GAC Filters (0.25 gpm, 5 Filters in Series)



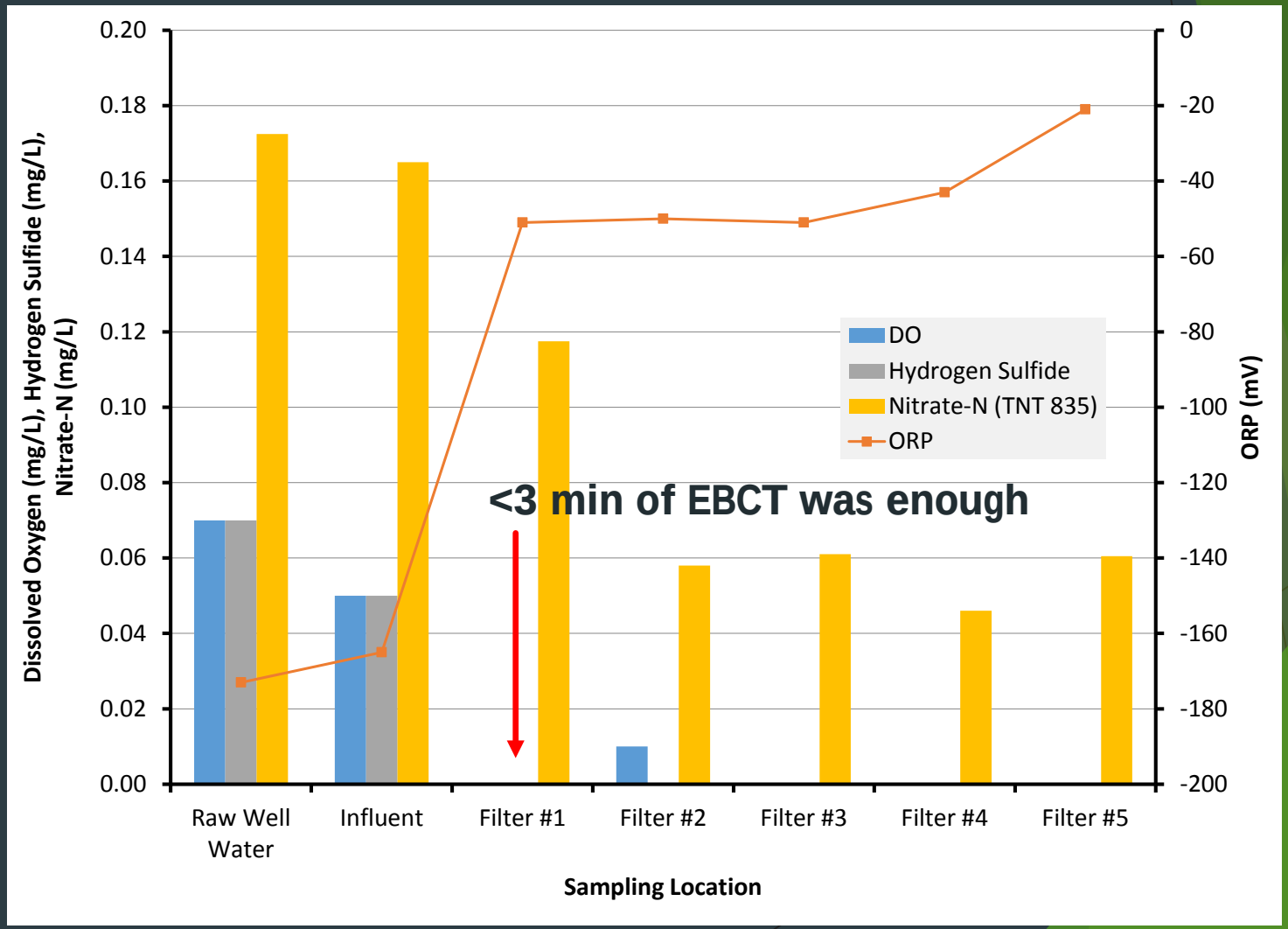
H_2S Removal in GAC Filters (0.25 gpm, 5 Filters in Series)



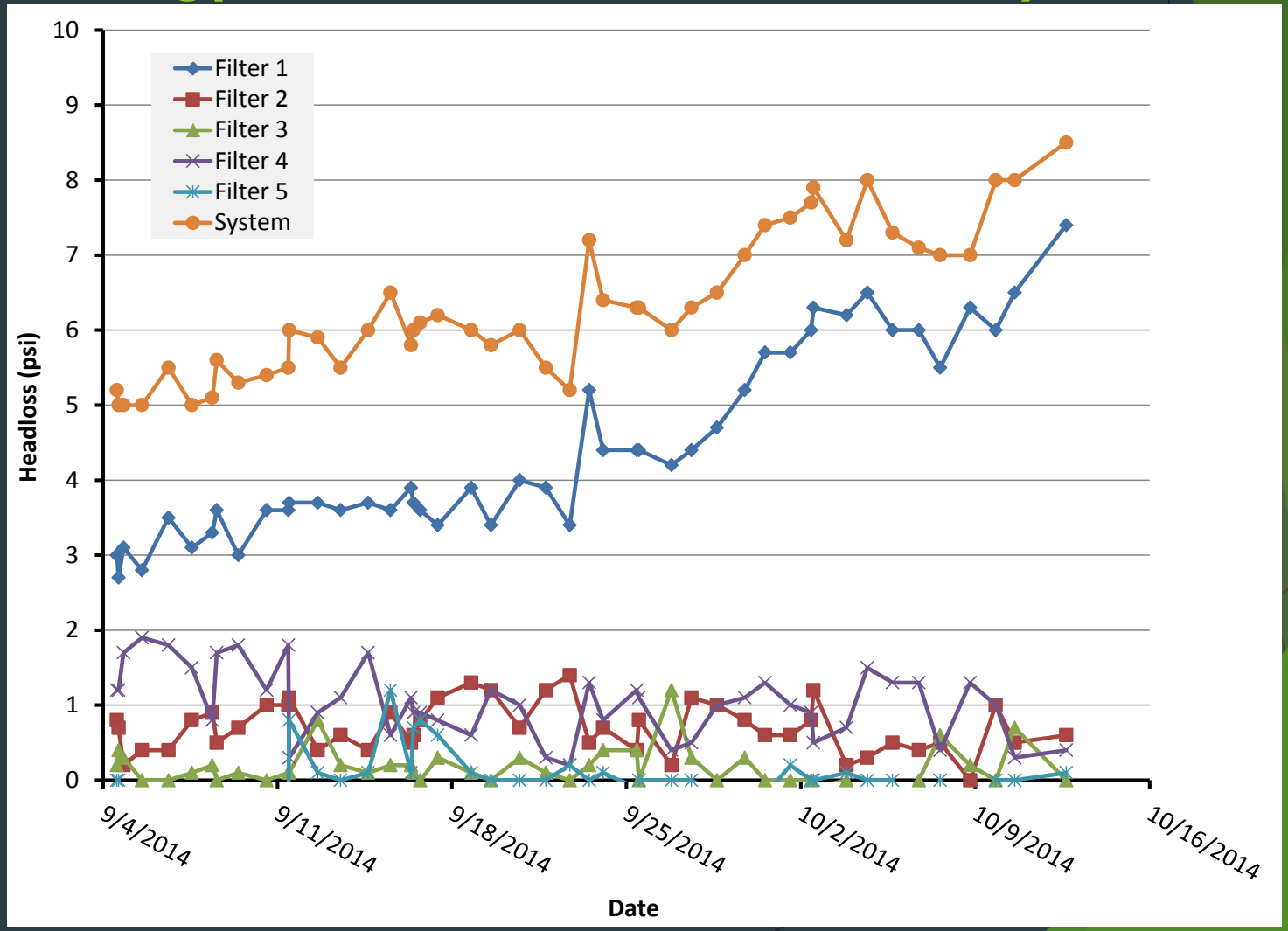
Color Removal in GAC Filters (0.25 gpm, 5 Filters in Series)



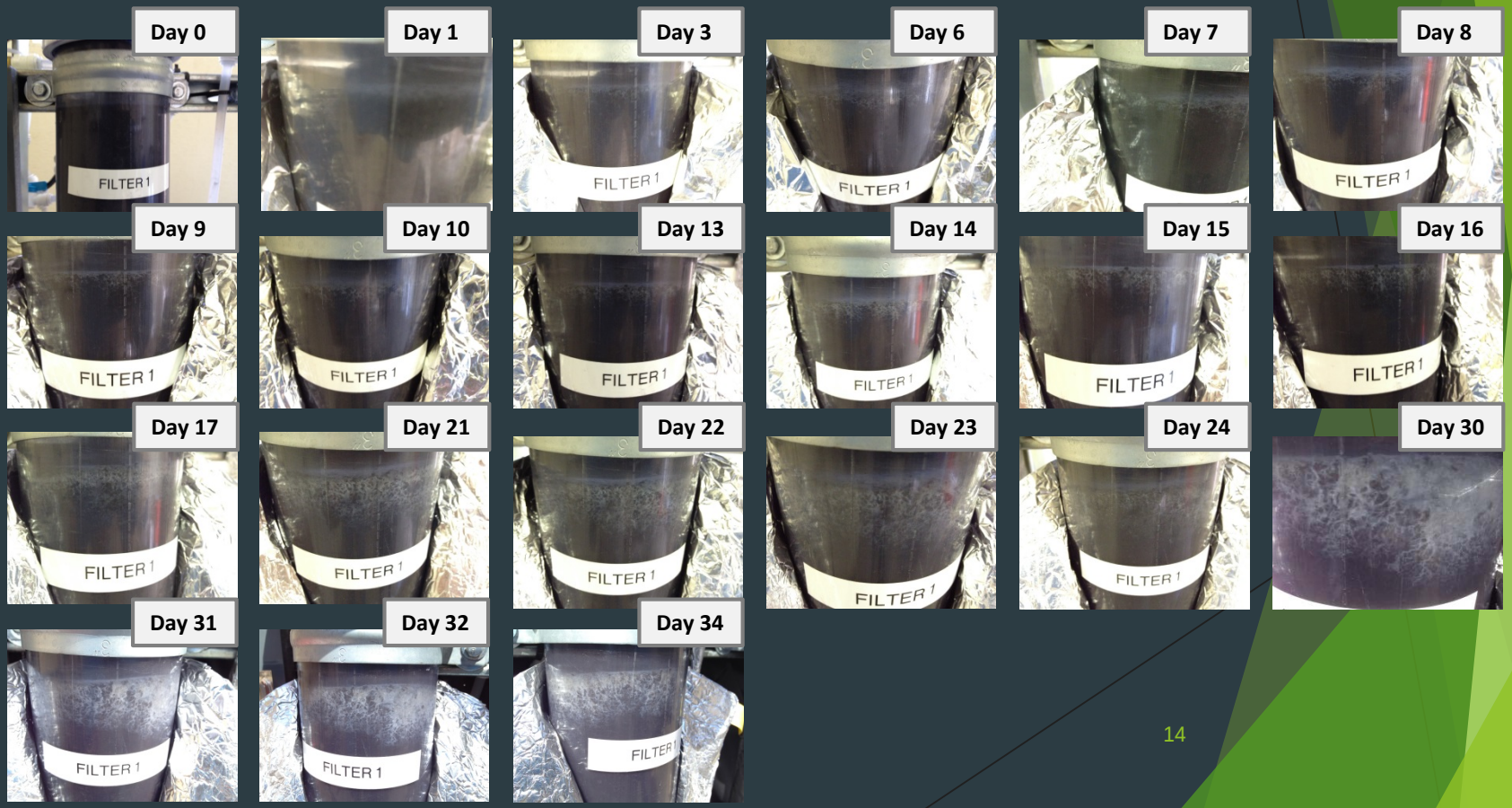
H_2S, DO, Nitrate-N, and ORP (0.25 gpm, 5 Filters in Series)



Head Loss in GAC Filters (0.25 gpm, 5 filters in Series)

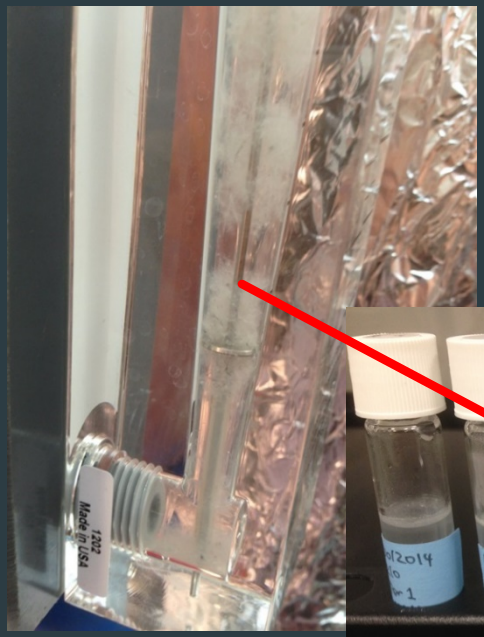


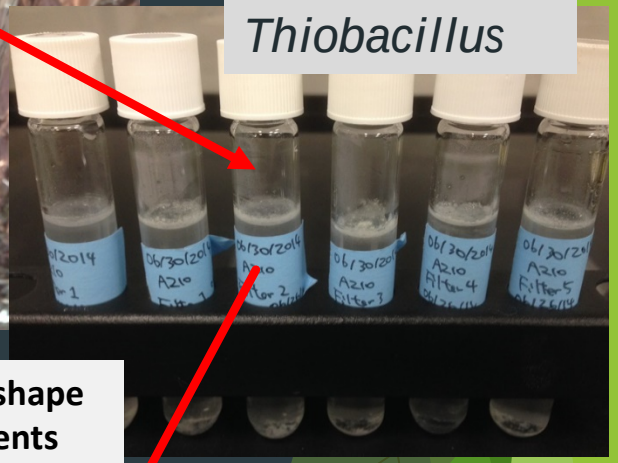
Colonization at the Surface of Filter 1 (0.25 gpm, 5 Filters in Series)



H_2S Removal Mechanisms

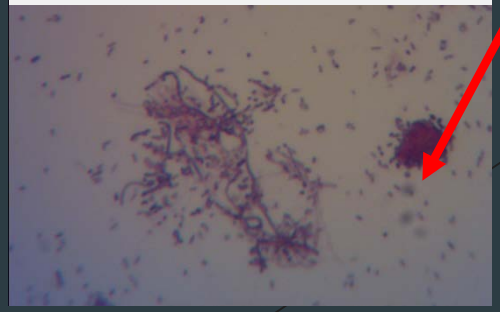
- Physicochemical
  - Adsorption/catalytic oxidation
    - Only at the start up (a few days)
  - Chlorine/Mn-mediated oxidation
    - No chlorine
- Biological
  - *Thiobacillus* spp.
    - Autotrophic denitrifier
  - *Thiothrix* spp.
    - Gram-negative, microaerobic sulfide oxidizer



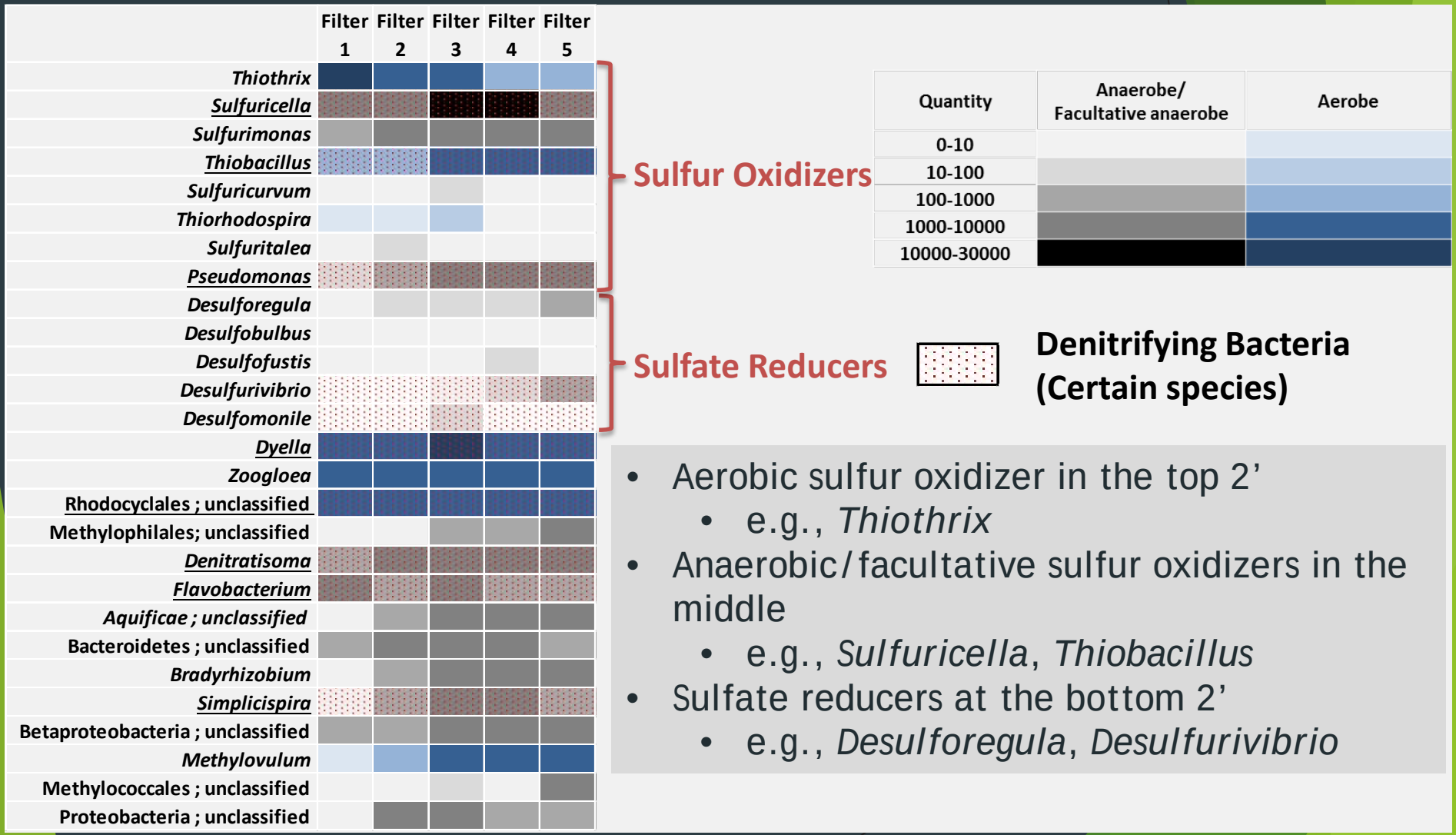


T2 Medium for *Thiobacillus*

Gram-negative, rod-shape cells forming filaments



16S rRNA Analysis

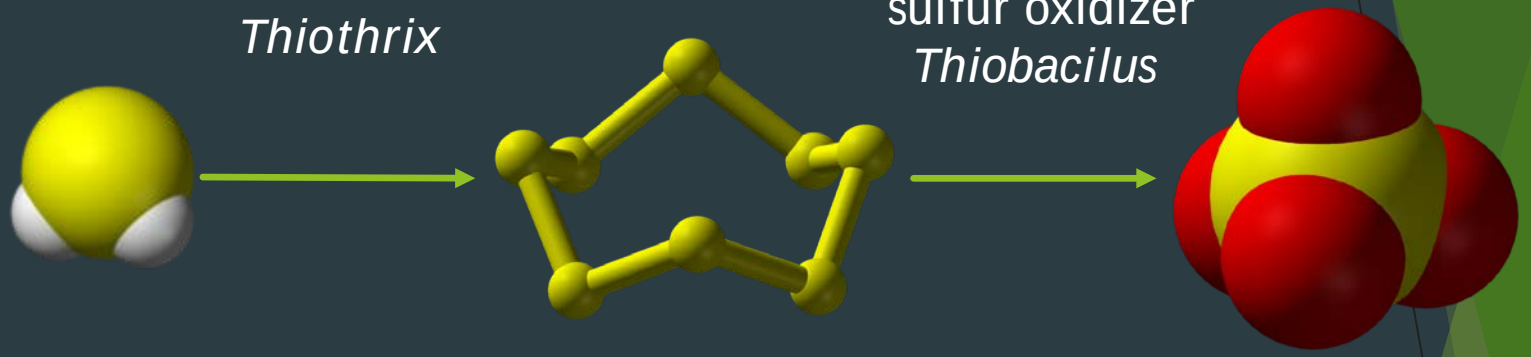


- Aerobic sulfur oxidizer in the top 2’
  - e.g., *Thiothrix*
- Anaerobic/facultative sulfur oxidizers in the middle
  - e.g., *Sulfuricella*, *Thiobacillus*
- Sulfate reducers at the bottom 2’
  - e.g., *Desulforegula*, *Desulfurivibrio*

Microbial Oxidation of H_2S (Hypothesis)

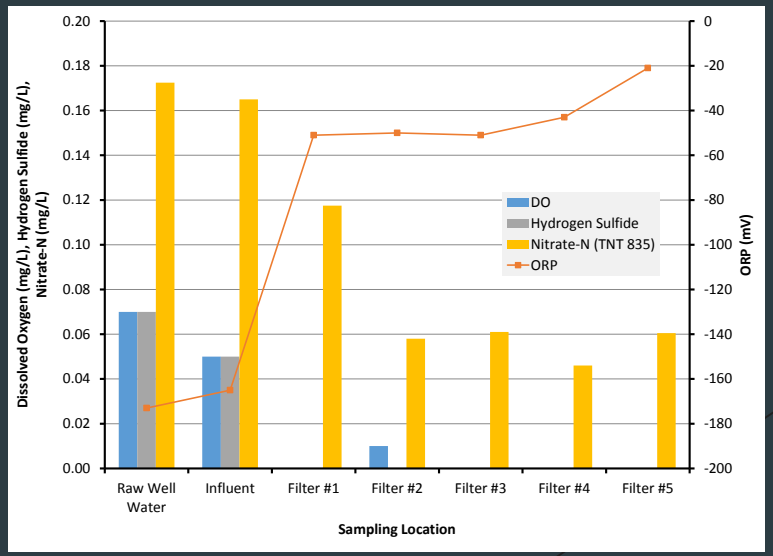
Aerobic sulfur oxidizer
Thiothrix

Anaerobic/Facultative sulfur oxidizer
Thiobacilus



Oxygen Consumption

Nitrate Consumption



Byproducts and Odor

- Elemental sulfur
- Polysulfides
  - Products of elemental sulfur and H_2S
  - HS_nH
  - Matchstick odor
- Elemental sulfur was detected in the Demo GAC filter effluent
- Polysulfide was non-detect
  - However, a very slight matchstick odor was present in some of the filter effluent samples
  - Need more sensitive sulfur analysis methods

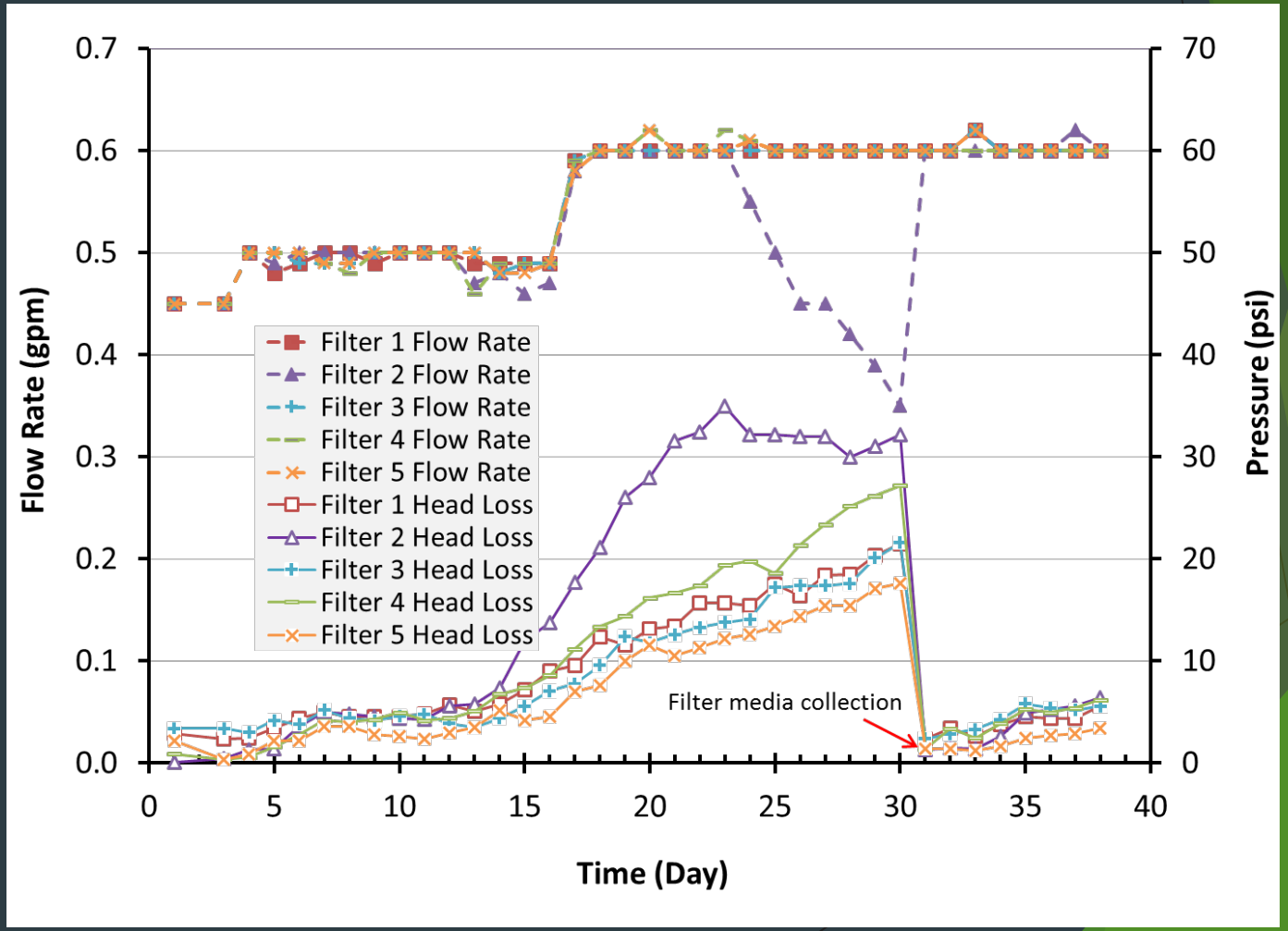
Odor Test
GAC + Chlorination

Current

Future

Incubation Time	Raw	Chlorinated-Fluoridated Raw	GAC Treated	Chlorinated-Fluoridated GAC Treated
<30 min	Strong rotten egg	Strong smoky/match stick	No odor	Strong bleach
3 hours	Weak rotten egg	Strong smoky/match stick	No odor	Bleach
6 hours	No odor	Strong smoky/match stick	No odor	Bleach
Implications	Hydrogen sulfide was present, dissipated during the incubation	Polysulfide was present, very persisting odor	No hydrogen sulfide/ polysulfide was present	No hydrogen sulfide/ polysulfide was present

High Flow Rate, Short EBCT (12.8 gpm/ft^2, 1.2 min, Parallel)



Conclusions

- GAC-based H_2S removal is feasible, repeatable, consistent and almost instantaneous
  - Coconut-shell based GAC
  - Worked at all three well sites
- No odorous byproducts before/after chlorination
- The primary removal mechanism is microbial
  - DO, ORP and nitrate are important parameters to monitor
  - Sulfate reduction may occur if the EBCT is too long
- Service flow rate can be as high as 13 gpm/ft^2
- EBCT can be as short as 1 min
  - Bed depth: Minimum 2'
  - Huge savings in capital and O&M costs
- The filters can be run for at least 3 to 4 weeks
  - Up to a few years (the demo filter at Well 9)
  - Backwash will remove excess biomass and elemental sulfur

THANKS

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