Impact of Anaerobic Biofilm Formation on Sorption Characteristics of Powered Activated Carbon

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SENER
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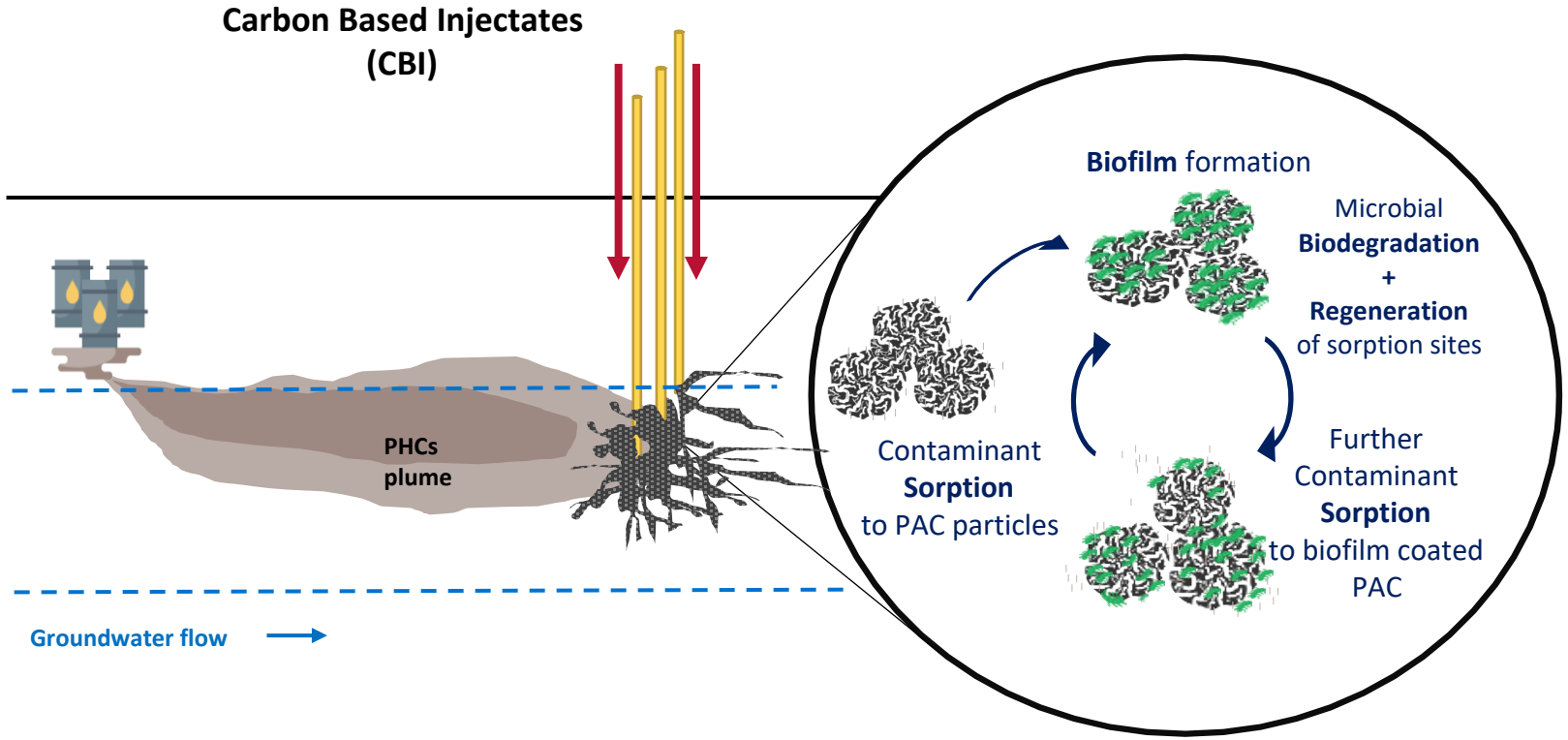
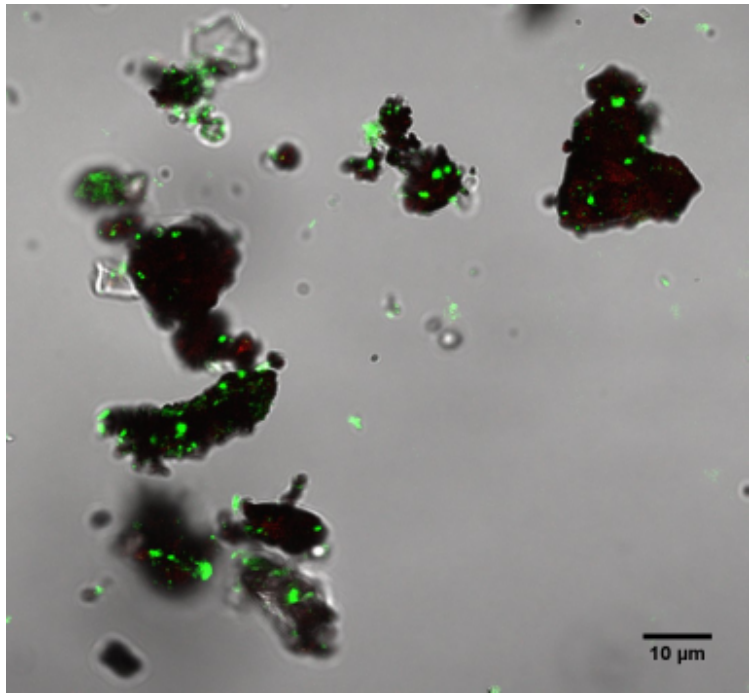
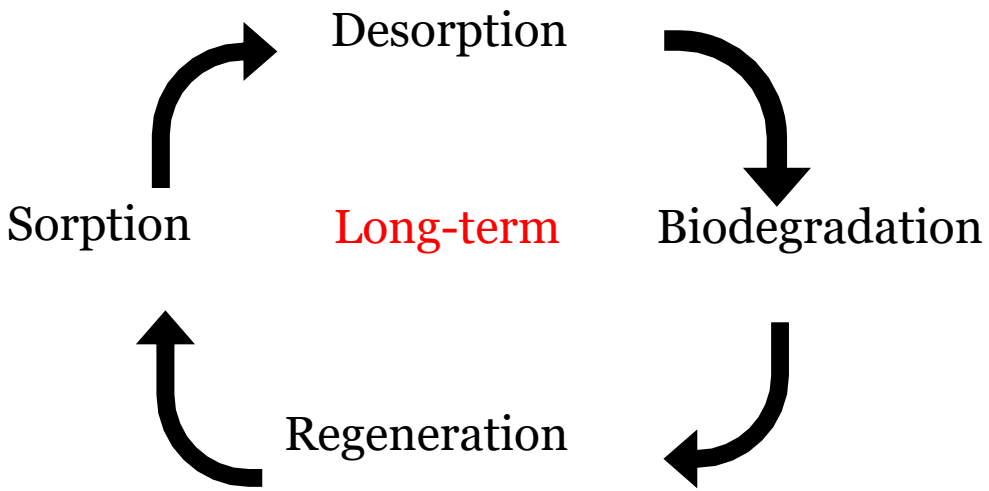
BACKGROUND
CARBON BASED INJECTATES FOR THE TREATMENT OF PHCs

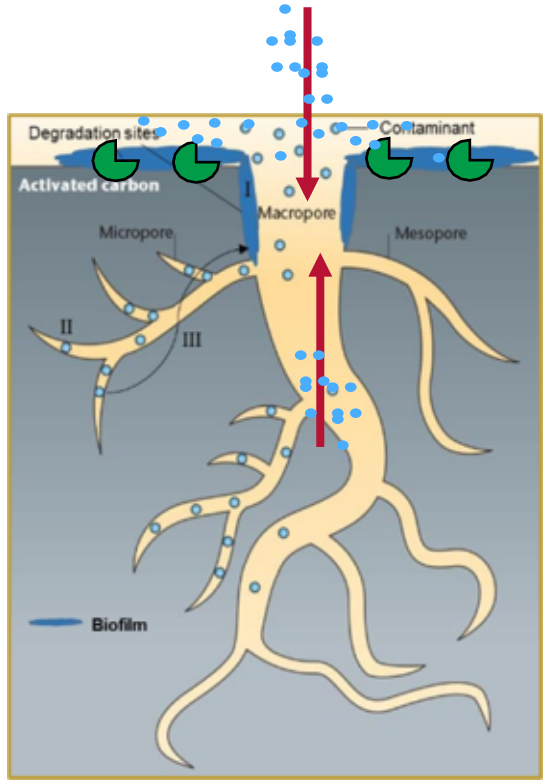




Field sediment samples with microorganisms attached to PAC particles.

BACKGROUND
BIODEGRADATION AND ACTIVATED CARBON

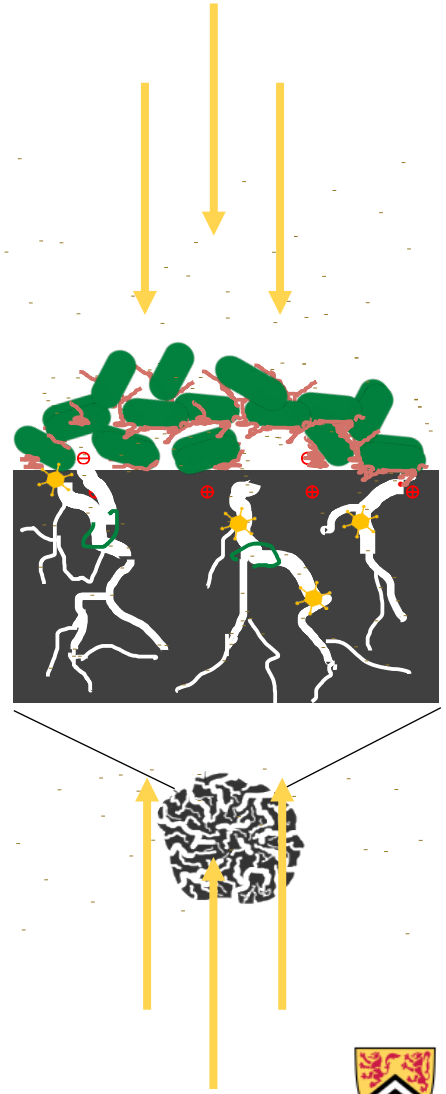




(Fan et al. 2017)

BACKGROUND
IMPLICATIONS FOR CBI

- Enhanced treatment
- Bioavailability
- Increased mass transfer resistance due to bioactivity:
  - Biomass
  - Lysed cells
  - Microbial by-products



RESEARCH HYPOTHESIS

A decrease in PAC sorption performance will occur as biofilm develops.

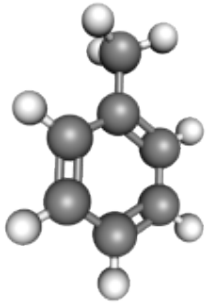
RESEARCH SCOPE

PHASE 1	• Baseline evaluation of sorption characteristics for the selected model PHC to fresh PAC.
PHASE 2	• Microbial activity monitoring: Establishment of anaerobic microbial biofilm on PAC and biodegradation of a model PHC.
PHASE 3	

PRINCIPAL MATERIALS

Sorbent: PAC WPC®, Calgon Carbon, < 325 US mesh.

Sorbate: toluene

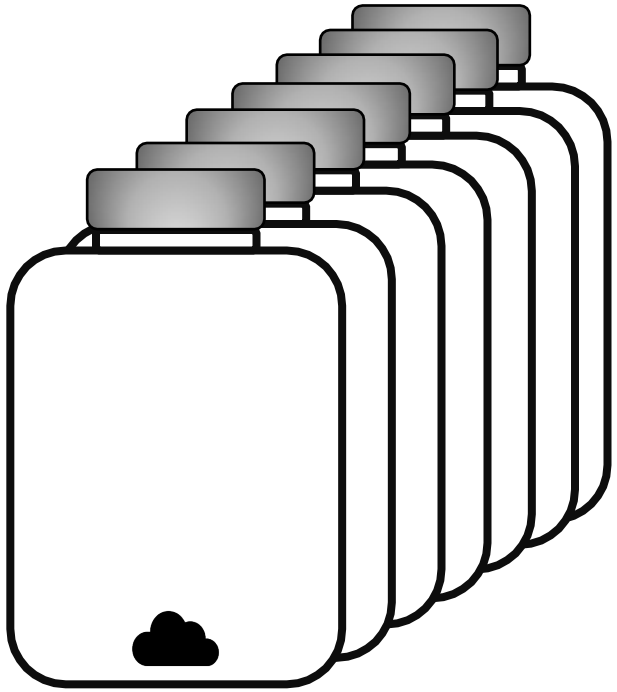


Microbial culture: DGG-T™ culture (Anaerobic toluene-degrading culture)

DGG T™

SiREM | siremlab.com

METHODS
BASELINE SORPTION EXPERIMENTS



Aqueous phase: AGW
Solid Phase (PAC): 10 mg dw

* Aqueous toluene concentrations ranged between 1 – 30 mg/L

Fresh PAC as sorbent material.

- Aqueous phase: Toluene
- Solid phase (PAC): Toluene

Freundlich isotherm model

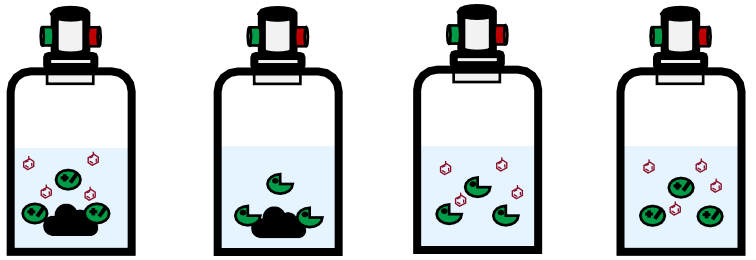
$$q_e = K_f \, C_e^{\,n_f}$$

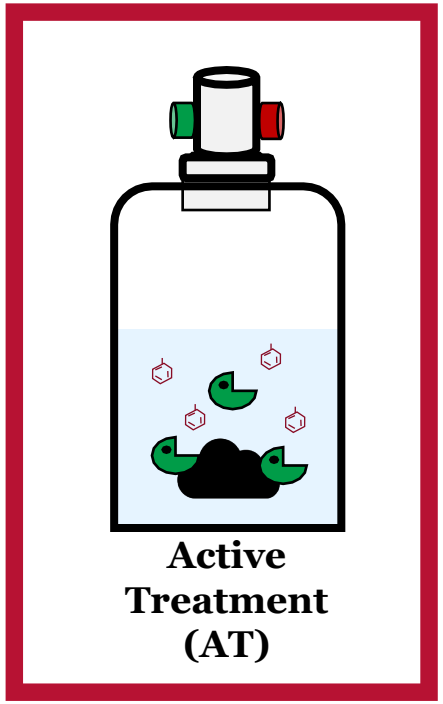
AGW: Artificial groundwater
dw: dry weight

METHODS
MICROBIAL ACTIVITY MONITORING: BIODEGRADATION

Anaerobic AGW
DGG-T culture: 10%
PAC: 10 mg dw

Experimental time : 180 days



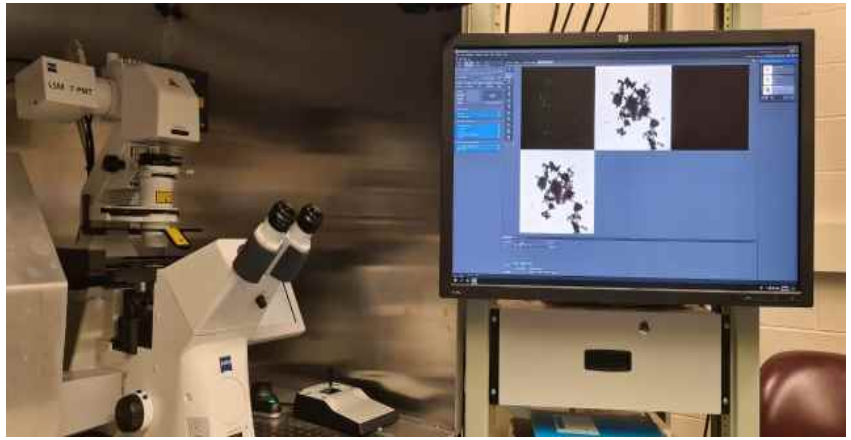


Bio-coated PAC

- Gas phase: CH_4, CO_2
- Aqueous phase: Toluene
- Solid phase (PAC): Toluene, biofilm

METHODS
MICROBIAL ACTIVITY MONITORING: ANALYSIS OF BIOFILMS

Sample staining
- SYTO9: microorganisms (nucleic acid stain)
- Concanavalin A: EPS (polyssacharides)

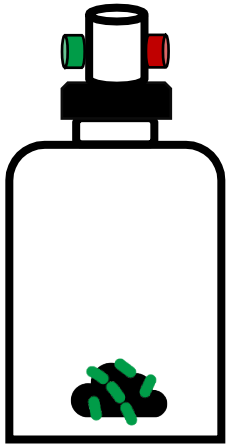


CLSM images

ImageJ + COMSTAT

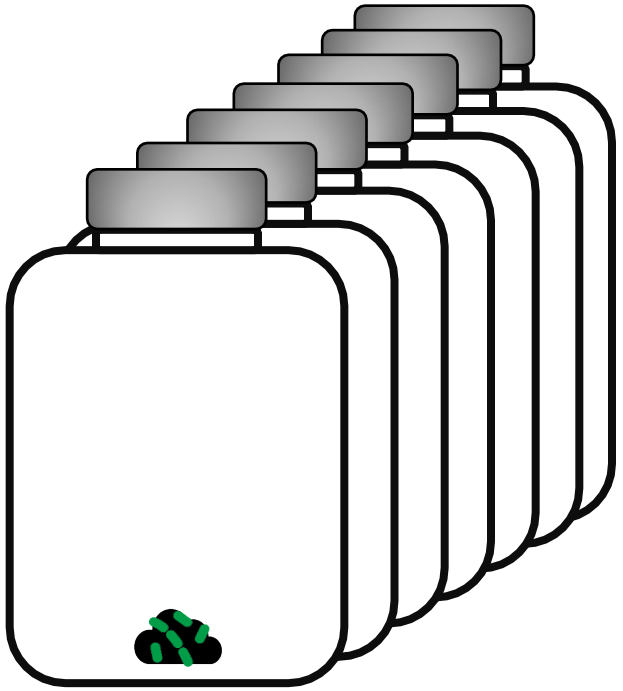
Qualitative
- General morphology
- Distribution

Quantitative
- Biovolume (μm^3)
- Biomass ($\mu m^3/\mu m^2$)
- Thickness (μm)



Active Treatment

METHODS
BIO-COATED PAC SORPTION EXPERIMENTS



Aqueous phase: AGW
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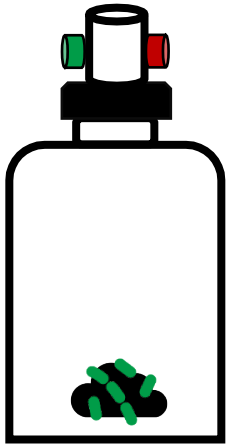
* Aqueous toluene concentrations ranged between 1 – 30 mg/L

Bio-coated PAC as sorbent material.

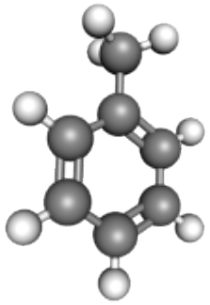
- Aqueous phase: Toluene
- Solid phase (PAC): Toluene

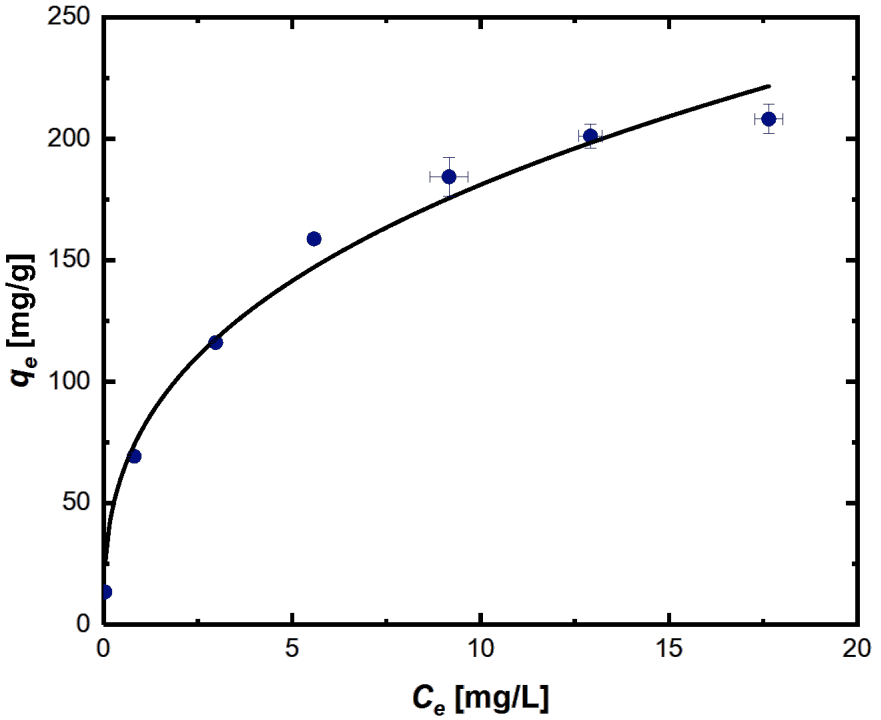


Active Treatment

$$q'_e = \frac{C_0 V_L + q_{0\,PAC} - C_e V_L}{m_A}$$

RESULTS
BASELINE SORPTION PERFORMANCE OF FRESH PAC

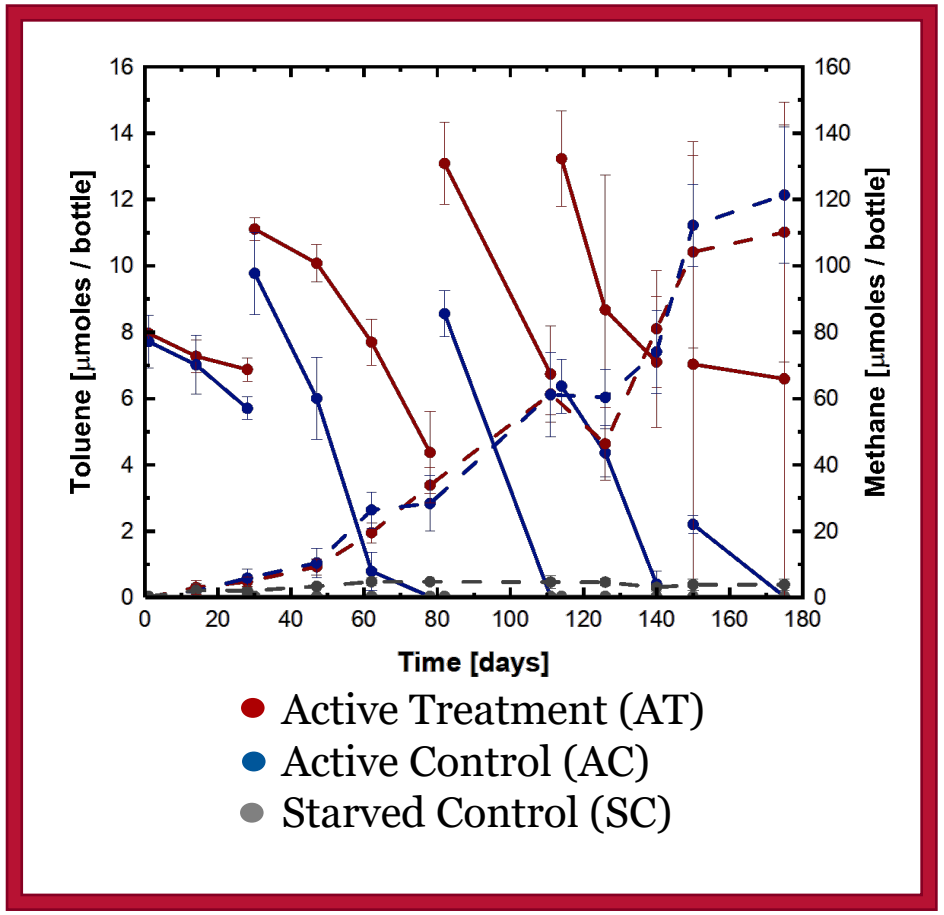


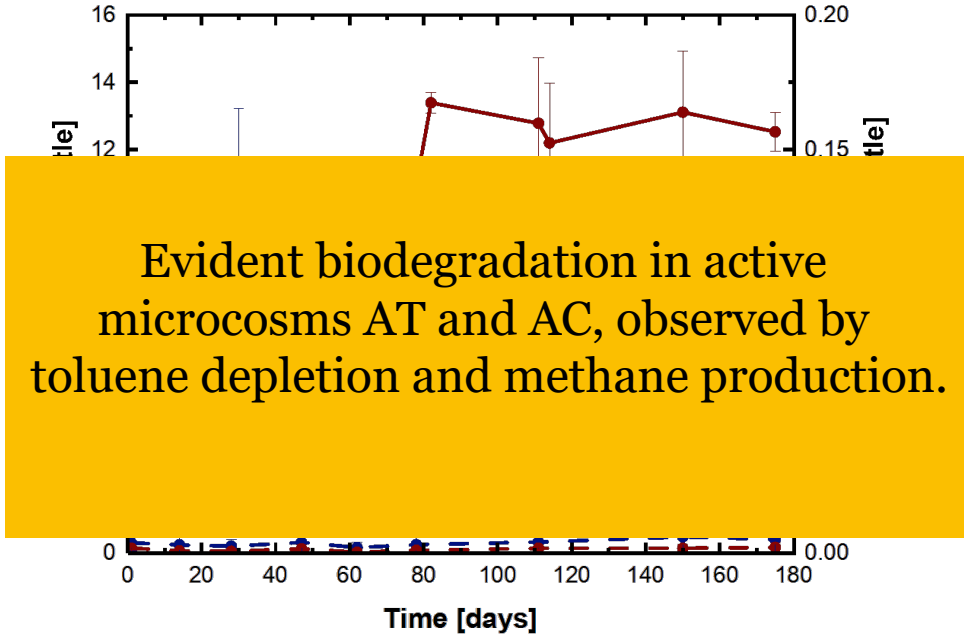


Sorption equilibium data for toluene on fresh PAC.

- Good affinity of PAC for toluene
- Favorable sorption of toluene to fresh PAC

RESULTS
MICROBIAL ACTIVITY: BIODEGRADATION

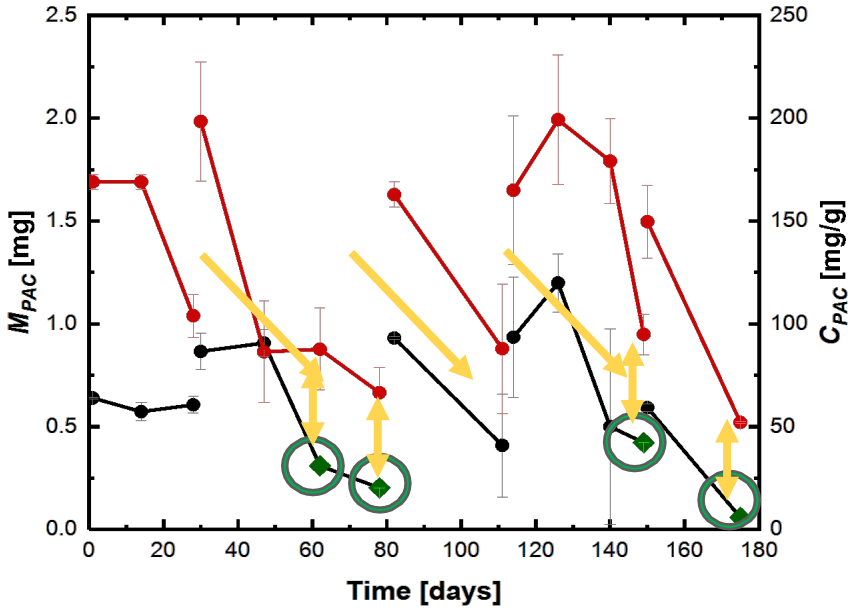




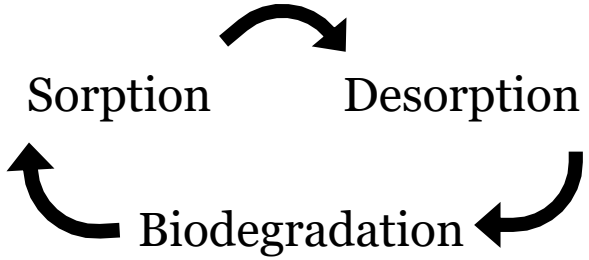
Evident biodegradation in active microcosms AT and AC, observed by toluene depletion and methane production.

Toluene mass (solid lines) and methane production (dashed lines) over the 180-day microcosm period. A gap in toluene profiles indicates a re-spike episode.

RESULTS
MICROBIAL ACTIVITY: BIODEGRADATION



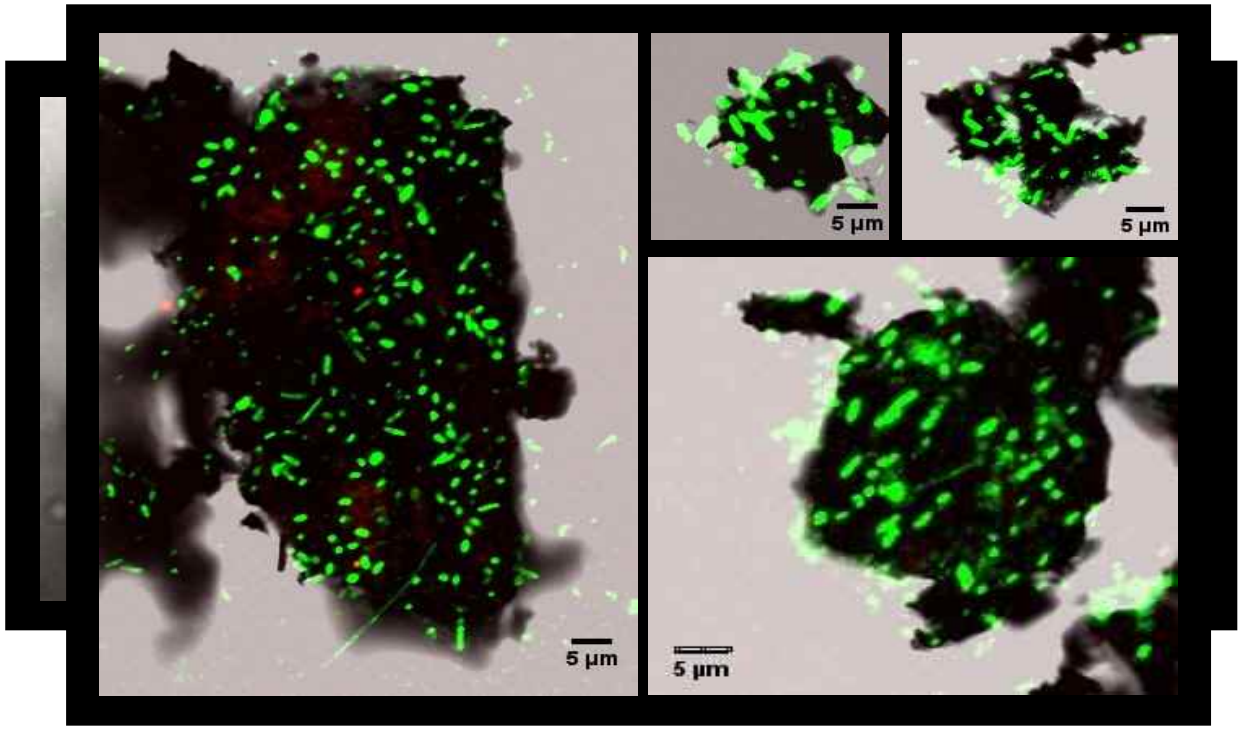
Mass (left Y-axis) and concentration (right Y-axis) of toluene sorbed to PAC over the 180-day period in the AT microcosms.



- ●: M_{PAC} and C_{PAC} estimated from mass balance
- ◆: M_{PAC} and C_{PAC} observed from PAC extraction
- ●: M_{PAC} and C_{PAC} estimated using the Freundlich model (Fresh PAC)

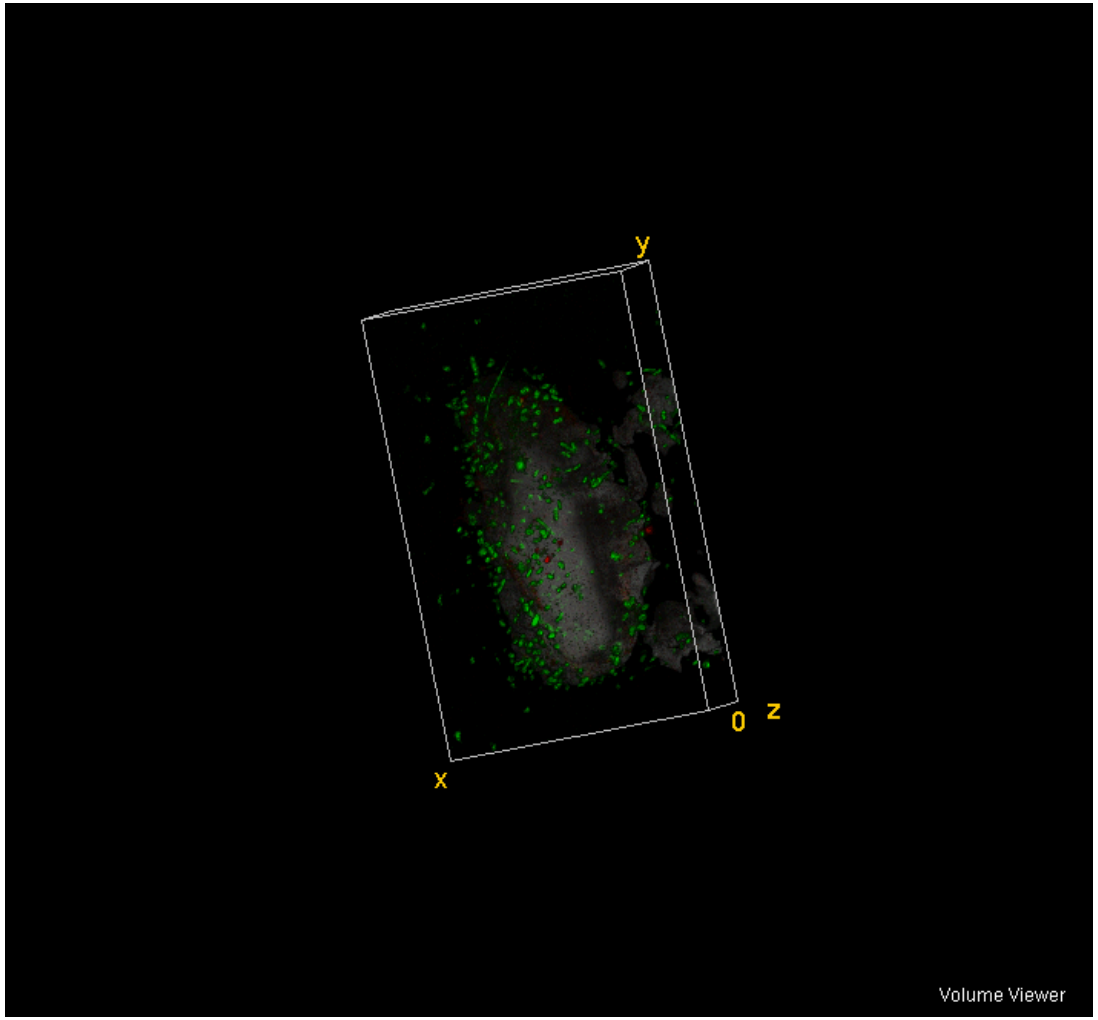
- Freundlich model (using fresh PAC parameters) overestimated the mass sorbed to PAC.
- **Evidence of toluene desorption from PAC** as a result of the decrease in aqueous phase concentration due to **microbial biodegradation**.

RESULTS
MICROBIAL ACTIVITY: ANALYSIS OF BIOFILMS



Day [illegible]o

Bacteria **EPS** **PAC**


y
z
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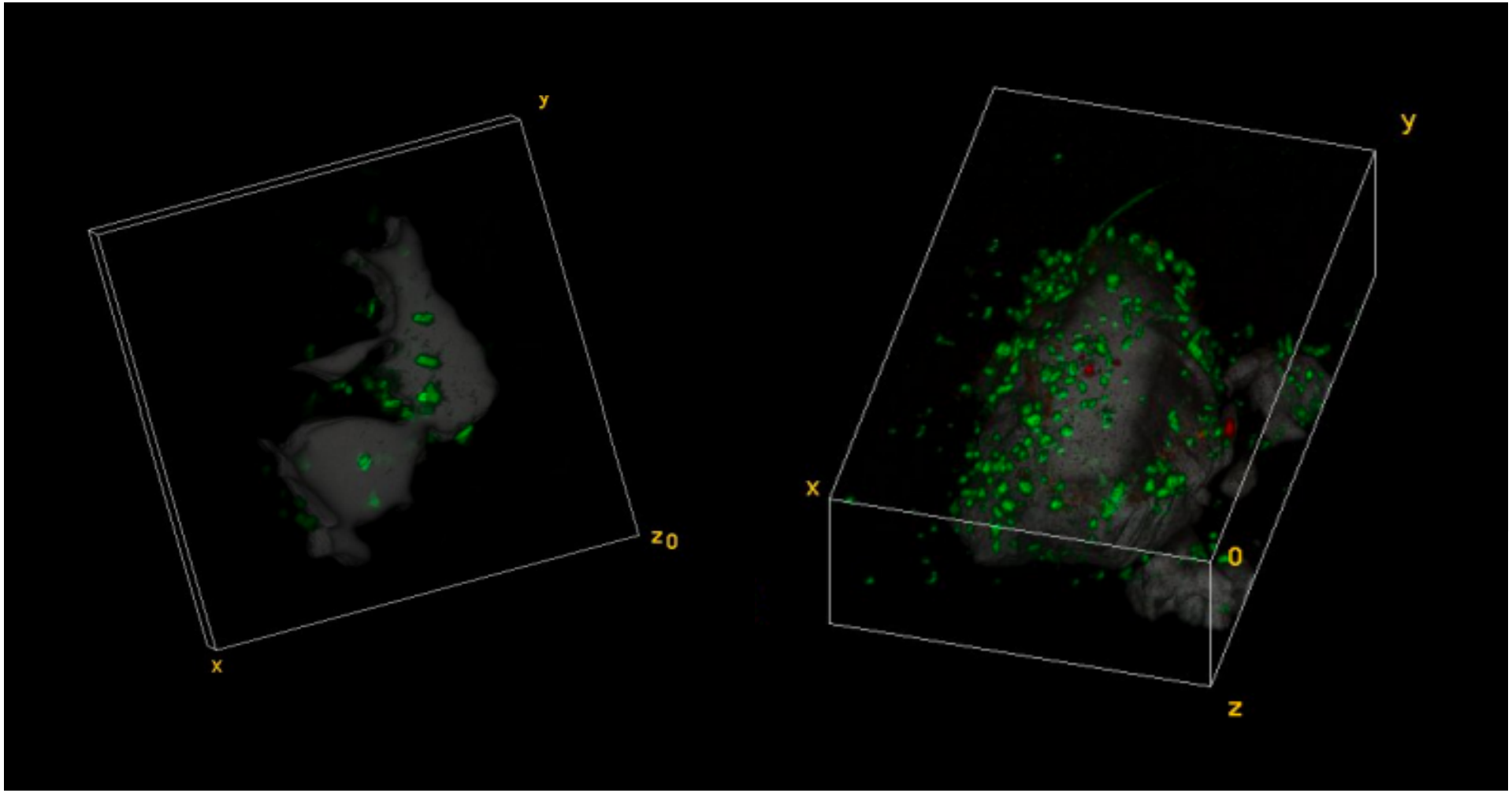
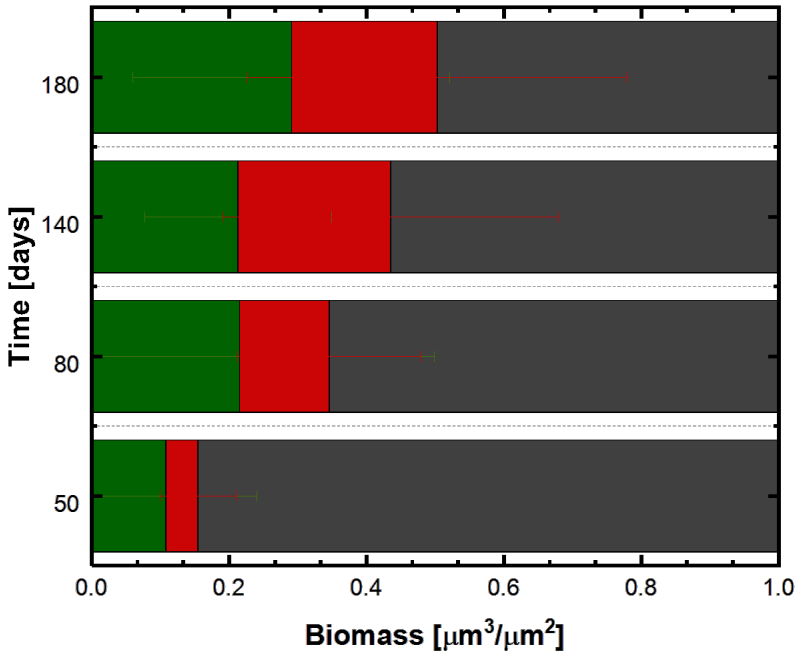
Volume Viewer

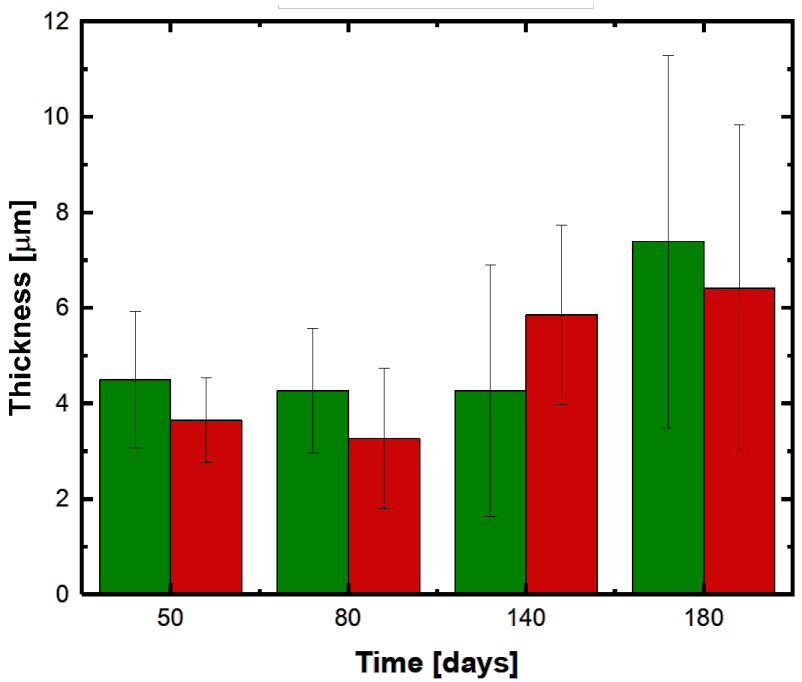
RESULTS
MICROBIAL ACTIVITY: ANALYSIS OF BIOFILMS



RESULTS
MICROBIAL ACTIVITY: ANALYSIS OF BIOFILMS



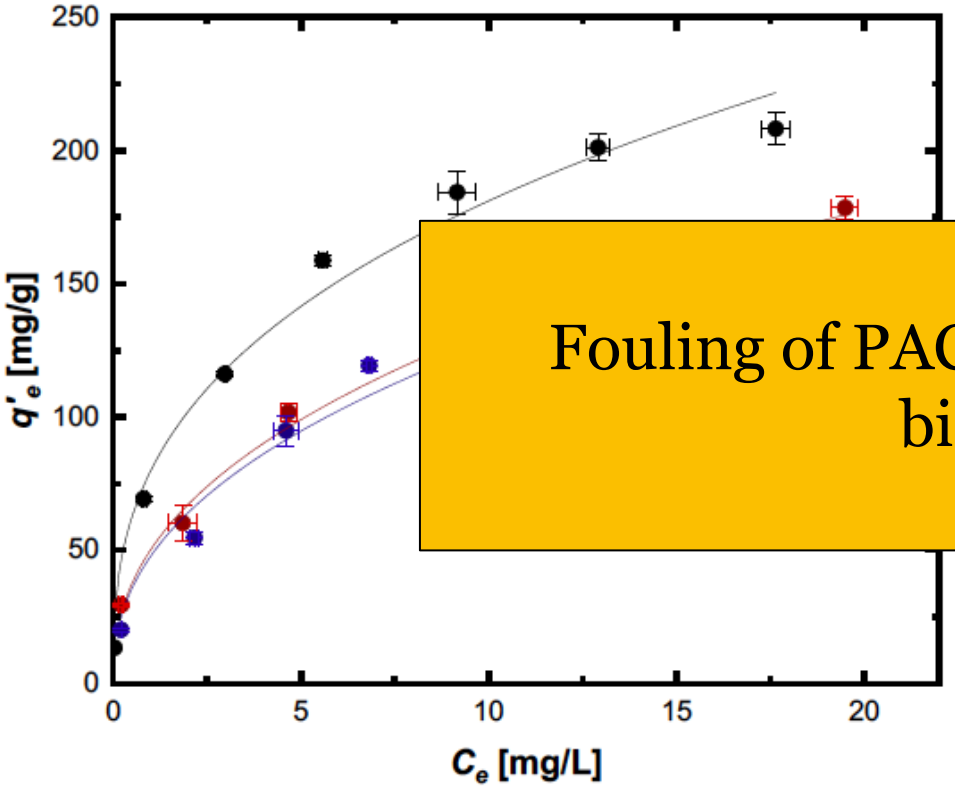
Biomass of cells and EPS of the anaerobic toluene degrading culture biofilm at different time points.



Thickness of cells and EPS of the anaerobic toluene degrading culture biofilm at different time points.

Bacteria **EPS**

RESULTS
EFFECT OF BIOMASS ON PAC SORPTION PERFORMANCE



Sorption isotherms for toluene on (●) fresh PAC, (●) bio-coated PAC after 80 days of growth , and (●) bio-coated PAC after 180 days of biofilm growth.

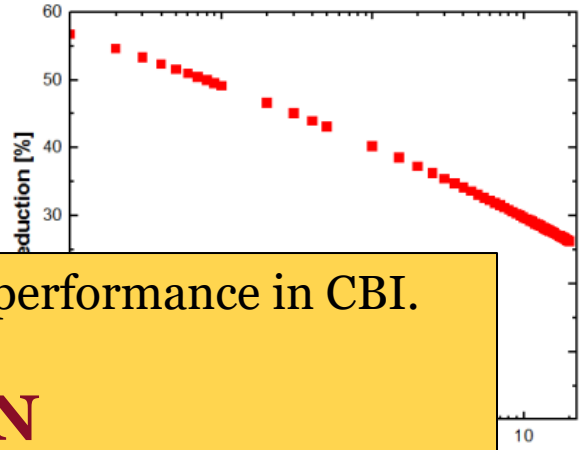
Fouling of PAC sorption sites due to bioactivity.

- ~40% reduction in sorption
  .
  ificant
  rption
  d Day 180.

IMPACT OF BIOFILM FORMATION ON MODELED PAC BARRIER

$$t_{sat} = \left[1 + \frac{\rho_b f_{PAC} K_f C_w^{n_f - 1}}{\phi}\right] \frac{L}{q}$$

$\phi = 0.3$
$L = 1\ \text{m}$
$q = 0.03\ \text{m/d}$
$f_{PAC} = 1\ \%$
$\rho_b = 1.8\ \text{g/cm}^3$

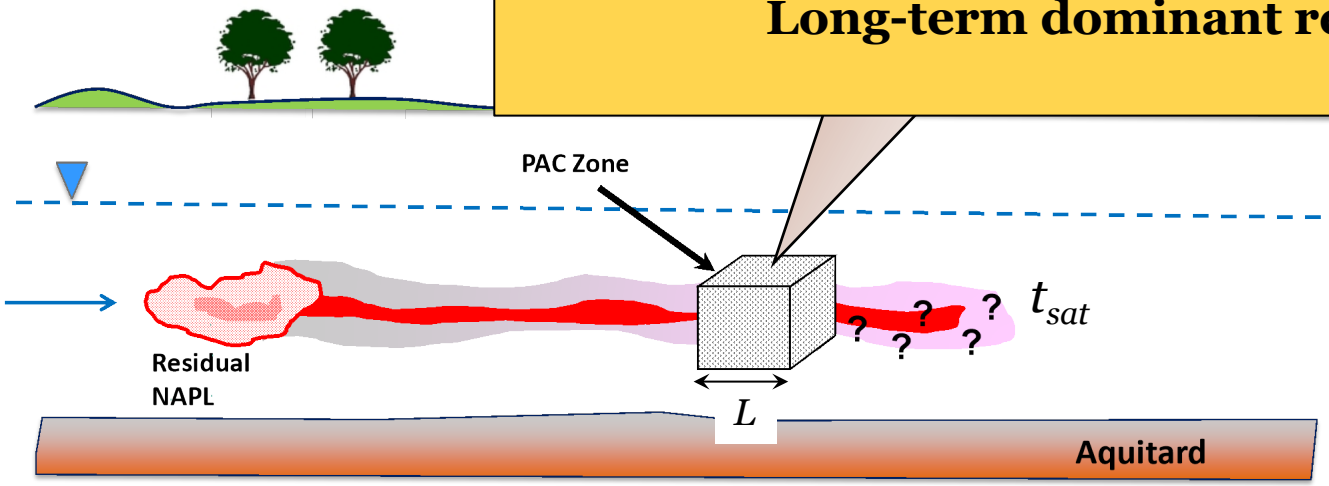


Reduction in t_{sat} does not imply loss of treatment performance in CBI.

BIODEGRADATION

Long-term dominant removal mechanism

t_{sat}) of bio-coated PAC at 180 days of biofilm growth compared to fresh PAC as a function of incoming concentration (C_w).



- The time to breakthrough of the PAC barrier deteriorated with biofilm formation.
- ~ 60% reduction in breakthrough time for a concentration of 10 µg/L.

CONCLUSIONS

Phase 1

- Baseline sorption performance on fresh PAC indicated its effectiveness to remove dissolved toluene from groundwater.

Phase 2

- Synergistic interplay between sorption, desorption and biodegradation.
- PAC is an efficient surface for microbes to form biofilms.
- Consistent growth of biofilm on the PAC.

Phase 3

- Observed change in PAC sorption characteristics for toluene due to the biofilm presence.

THANK YOU