MABR Workshop: Current Status and Emerging Applications

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December 6, 2020
11:00 – 12:30 (GMT-05:00)

UM Environmental Biotechnology

COLLEGE OF ENGINEERING
CIVIL & ENVIRONMENTAL ENGINEERING
UNIVERSITY OF MICHIGAN

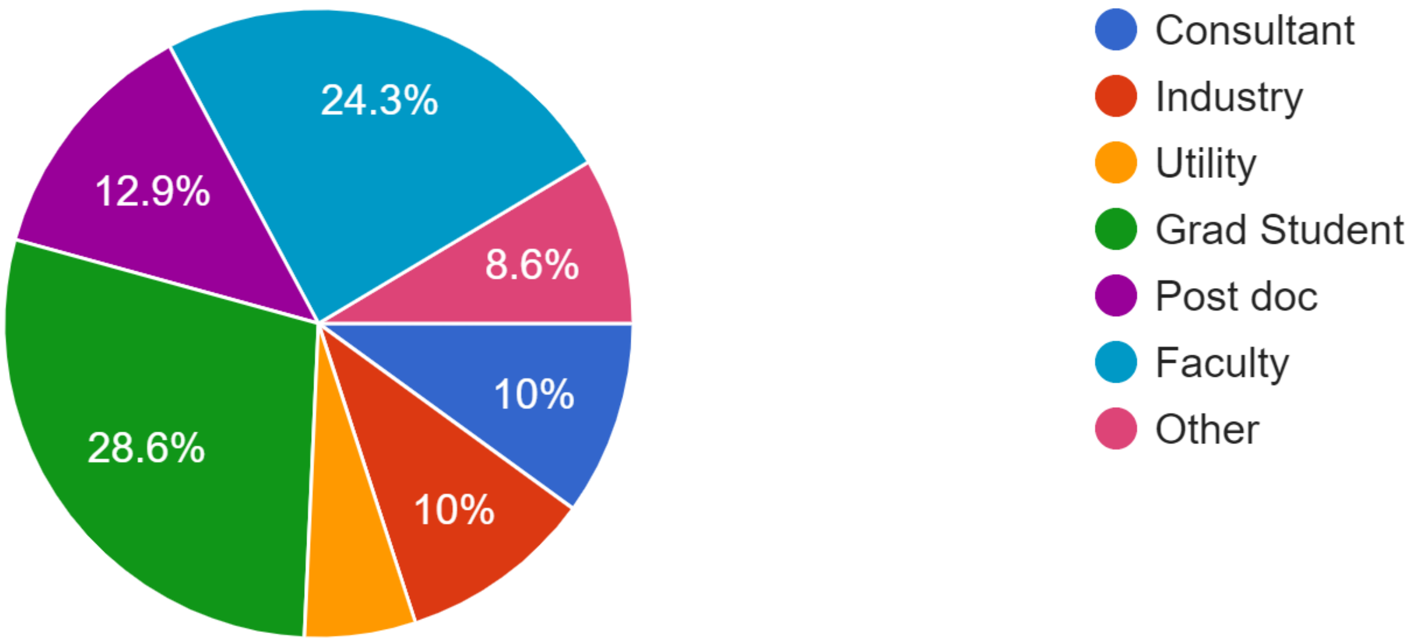
Objectives for This Workshop Include:

1. Update Participants on Current Status of MABR Technology, Including:
   a. What the Technology is
   b. Existing Applications
   c. Emerging Applications
2. Identify and Share New Ideas Concerning Potential Applications
3. Identify Knowledge Gaps to Support Expanded Applications and the Research and development Needed to Address Them

Participants Were About Two-Thirds Academic & One-Third Practice

Job category

70 responses



Workshop Agenda

11:00 – 11:30: Introductions and Overview Presentations

- **Overview of Workshop and Workshop Objectives**
- **Overview of MABR Technology, Rob Nerenberg, University of Notre Dame**
- **Overview of Typical Applications: Dwight Houweling, Suez Water Technologies & Solutions**

11:30 – 11:55 and 11:55 – 12:15: Two Rounds of Breakout Sessions. Titles and Facilitators

- ***Imagining the Future – Exploring New Applications for MABR*; Jeff Peeters, Suez Water Technologies & Solutions**
- ***MABR Process Engineering: What We Know for Sure, What we are Still Contemplating;* Ronen Shechter, Fluence**
- ***MABR Biofilm Thickness Control;* Barry Heffernan, Oxymem**
- **Modeling MABR's; Kelly Gordon, Black & Veatch**

12:15 – 12:30

- **Reconvene and Summarize Outcomes**

Indicate Preferred Breakout Session Using Link in Chat

Those Who Were Crucial with Logistics:

- Patricia Perez Calleja, Notre Dame
- Yi Cao, U-M
- Avery Carlson, U-M
- Emily Clements, Notre Dame
- Huanqi (Haley) He, U-M
- Changyoon Jun, U-M
- Bumkyu Kim, Notre Dame
- Daehyun (Danny) Ko, U-M
- Brett Wagner, U-M
- Cheng Yang, U-M

Imagining the Future – Exploring New Applications for MABR

- **Main commercial application today is increasing capacity and/or improving nutrient removal in existing tanks**
- **MABR mimics biology – transfer of O2 and nutrients from the inside rather than outside**
- **New/future application ideas**
  - **Improving current application**
    - **MABR in aerobic (or swing) reactors**
    - **Integration with EBPR (in biofilm or in suspension)**
    - **Shifting share of biofilm in hybrid process from 25-50% of treatment to 80%+… is there a limit wrt biofilm thickness control?**
    - **Peak trimming**
  - **New applications in wastewater treatment**
    - **MABR enabled AMX – mainstream & sidestream**
    - **N2O mitigation and/or recovery**
    - **MABR in a water reuse system, e.g.; in combination with MBR**
    - **Effluent ammonia polishing, e.g.; overcome high energy costs for MBBR (mixing limited)**
  - **New applications outside wastewater treatment**
    - **Transfer of H2, e.g.; biogas**
    - **Transfer of CO2, e.g.; algae, alkalinity**

MABR Process Engineering: What We Know for Sure, What we are Still Contemplating

- Mixing intensity not just for scouring (biofilm control) but also influences mass transfer
- Questions about achieving low effluent ammonia. Staging? Removal in downstream stages?
- Balancing season variations in microbial community
- Start-up
  - For hybrid system just add to mixed liquor
  - For MABR alone will take time
- Designing for TN removal
- Phosphorus removal
  - Understandable in hybrid system
  - May be more difficult in straight MABR process

MABR Biofilm Thickness Control

- Biofilms differences in MABR and Hybrid MABR Processes
  - Carbon processing by biofilm versus suspended growth for two systems creates differences
  - Thinner biofilms tend to develop in hybrid systems and may be lower heterotroph population
  - Biofilm thickness control important to avoid mass transfer limitations. Reduced nitrification with biofilm that is too thick. But, oxygen requirement does not increase because increased denitrification with thicker biofilm
  - Loading tends to affect biofilm thickness
- Biofilm control
  - Oxymem
    - Separate aeration and scour blowers
    - Use inert gas (Argon) and pressure decay test to measure biofilm thickness and scour blowers to control thickness
  - Suez
    - Collect aeration air below membranes and pulse through membrane pack to scour
- Excess biofilm development does not lead to structural failure. But, creates a resistance to flow through the biofilm bundle that is necessary to expose biofilm to influent substrate
- Hot air does not lead to increased temperature in biofilm

Modeling MABR’s

- Model complexity in terms of runtime and accuracy
  - Layers vs. continuum
  - Biomass density
  - Solids attachment and detachment
  - Simplified model and machine learning
- Will <u>void space</u> disturb modeling?
- How is <u>aeration modeled</u> and what is the impact of <u>scouring</u>? How does this result with modeling biofilm thickness – it makes everything complicated!
  - Do you have continuous vs. discontinuous scouring?
- Importance of attachment/detachment
  - Interlayer mixing
  - Seeding
  - Biofilm thickness
  - Scouring
- Seeding and initial conditions

Biofilms 2020 Virtual Conference

Emerging Trends and Developments

Dec 7 – 9, 2020

the international water association

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Rob Nerenberg

rnerenbe@nd.edu

MABR Workshop

Overview of MABR Technology

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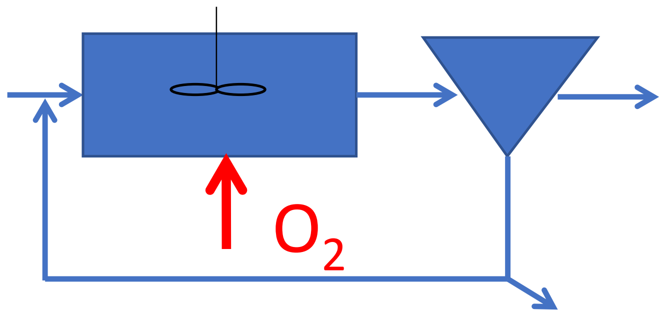
Overview

- Why MABRs?
- Unique behavior
- Research needs/interesting observations
- Summary

1. Why MABRs?

Activated Sludge



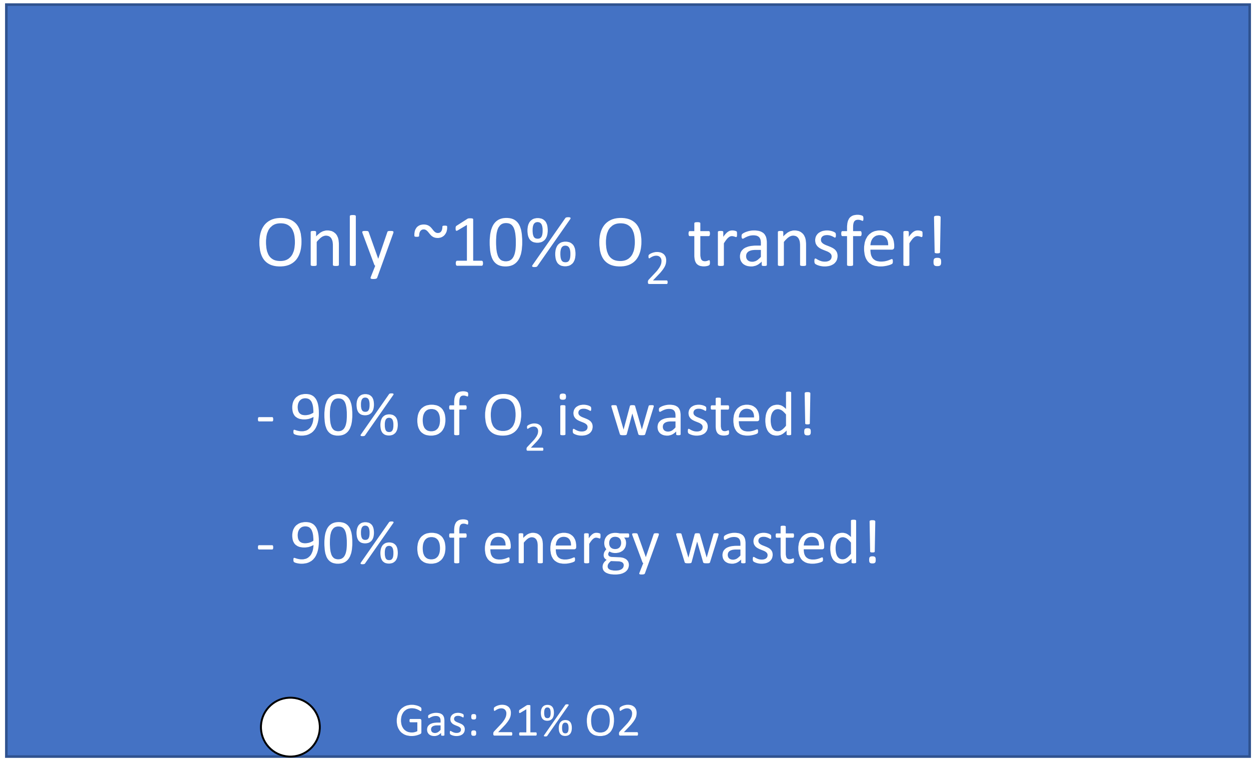
hydrotecsolutions.com

Aeration consumes 50-90% of power

Oxygen transfer efficiency (OTE) only 10 – 25%

Bubbled aeration

Gas: 19% O_2



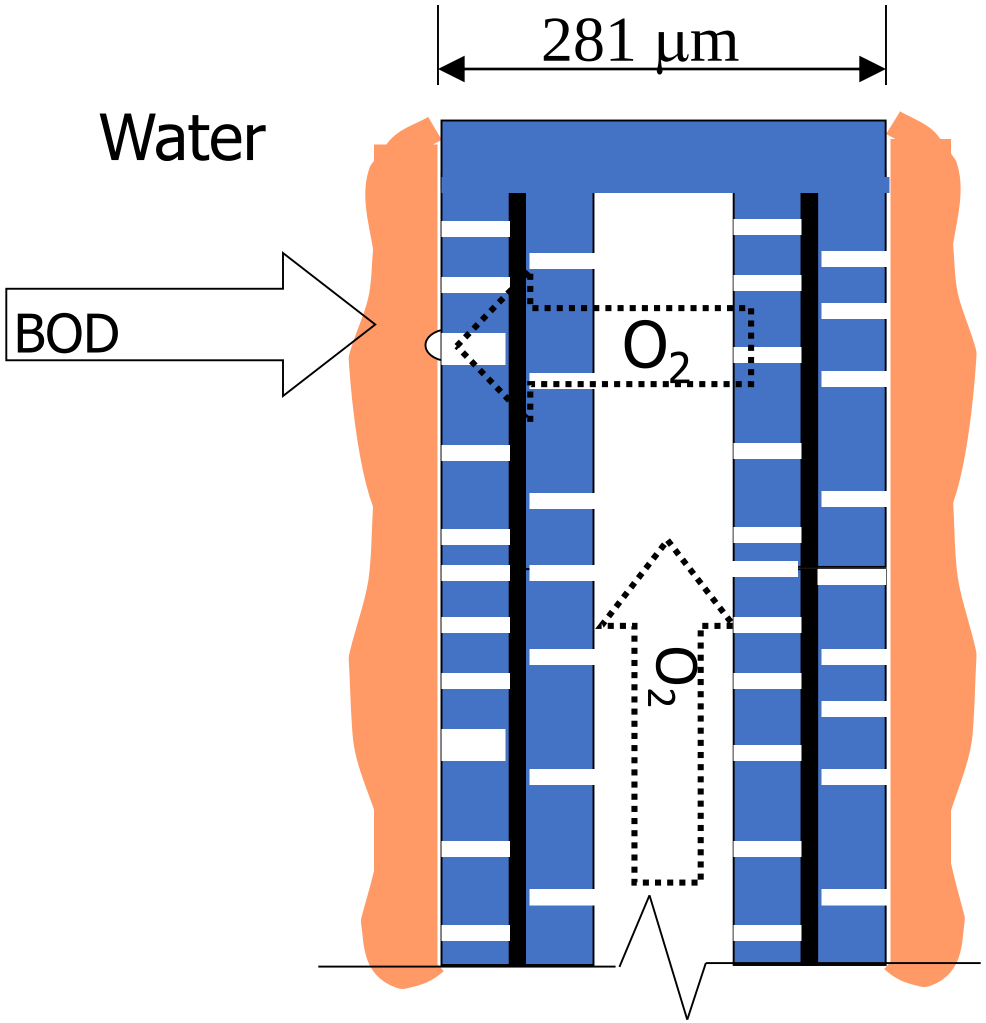
What if we could create a “stationary” bubble?

100% O_2 transfer!
Less air required!
Less energy required!

Biofilm formation?

Membrane-Aerated Biofilm Reactor (MABR)

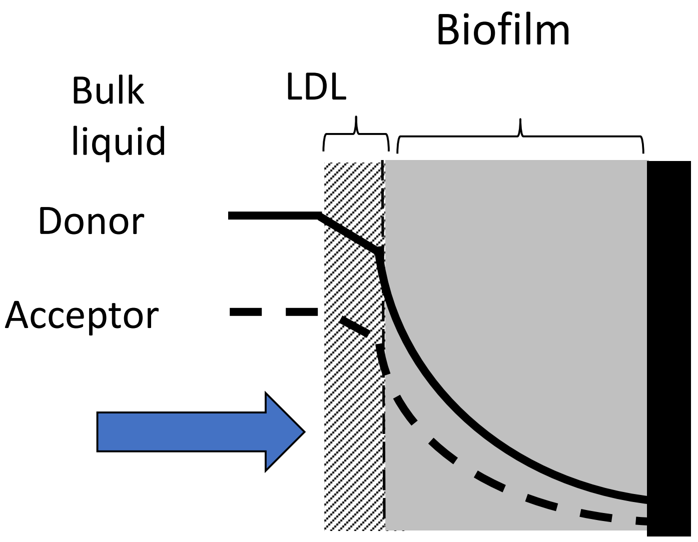
- Up to 100% OTE
- Low energy consumption
- "On demand" O_2 supply
- High specific surface area allows small footprint



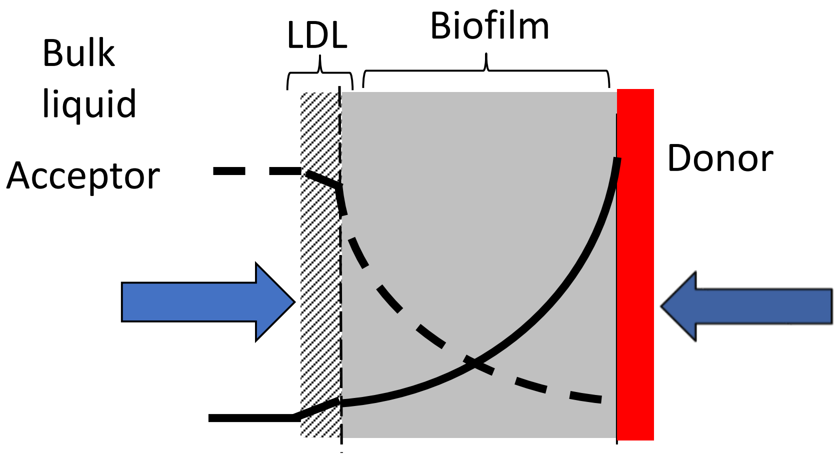
2. Unique Behavior of MABRs

Biofilms

Co-Diffusional Biofilm

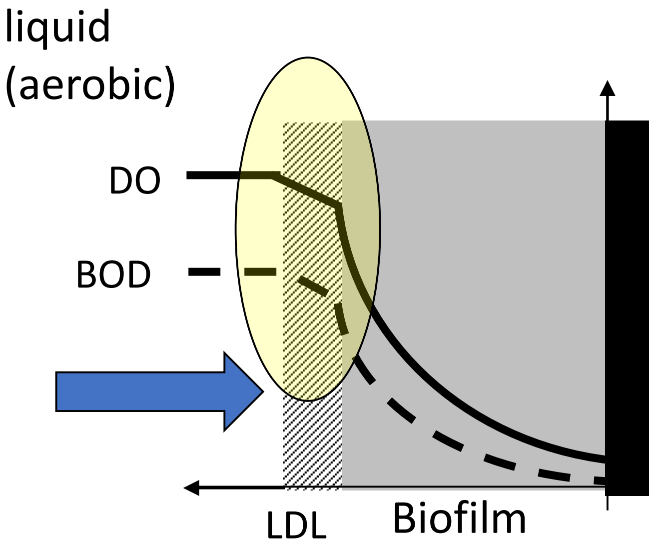


Counter-Diffusional Biofilm

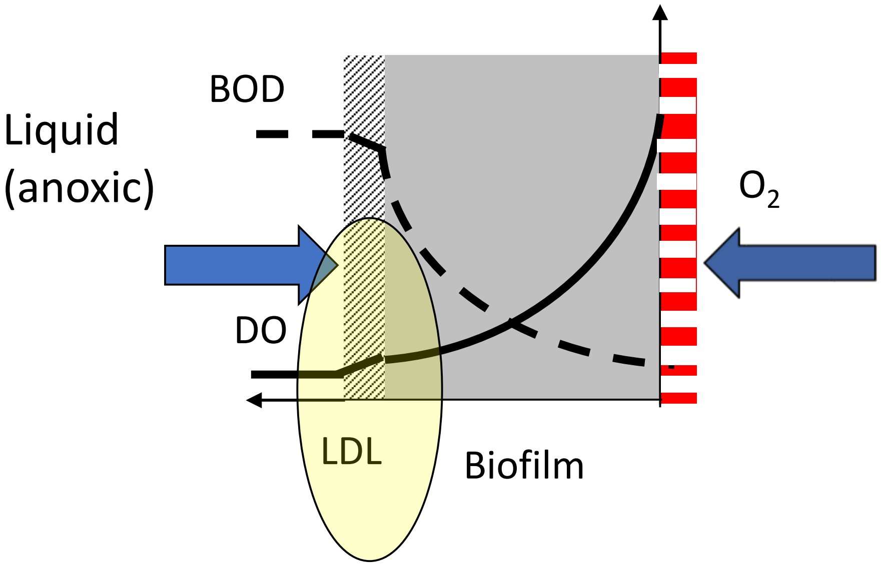


What is special about counter-diffusional biofilms?

1. Liquid diffusion layer retains “internal” substrate



Conventional biofilm

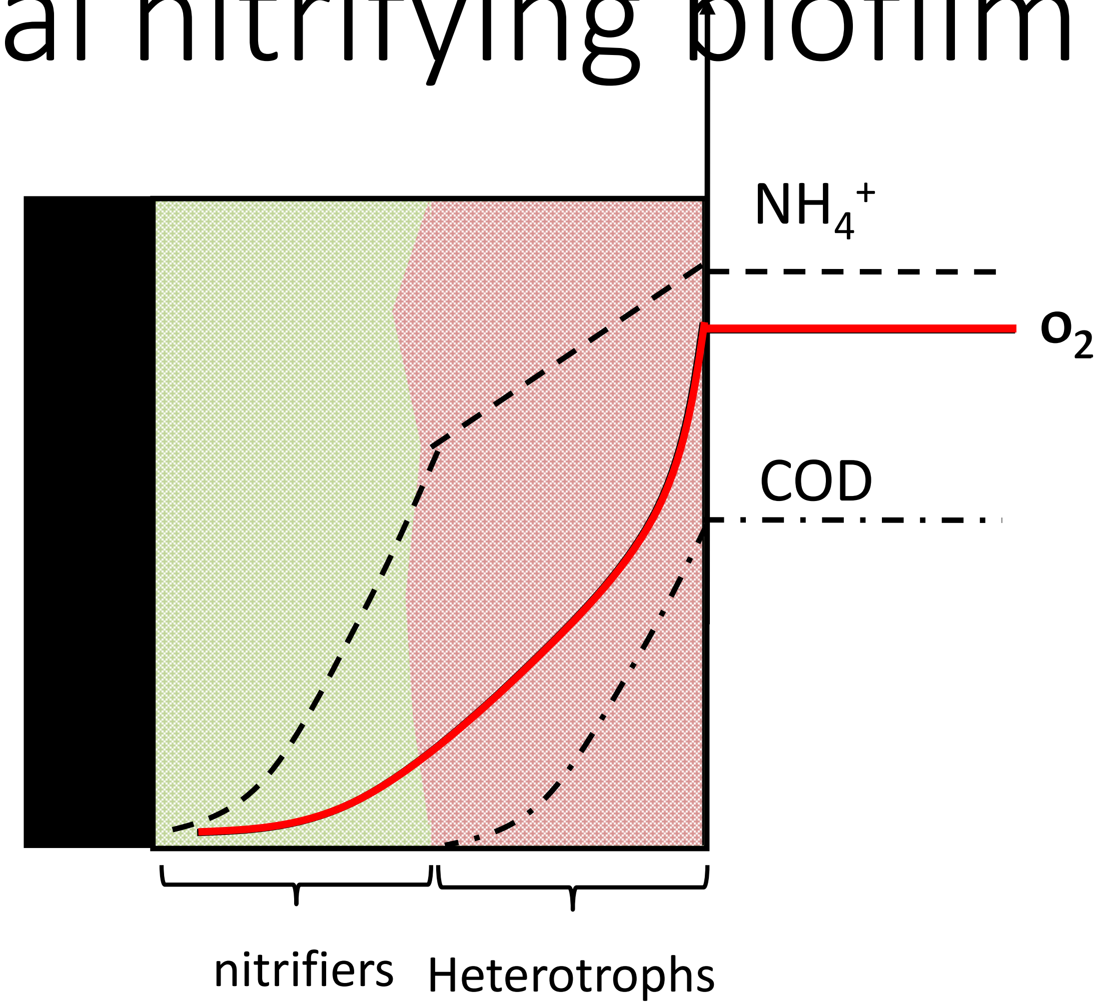


Counter-diffusional biofilm

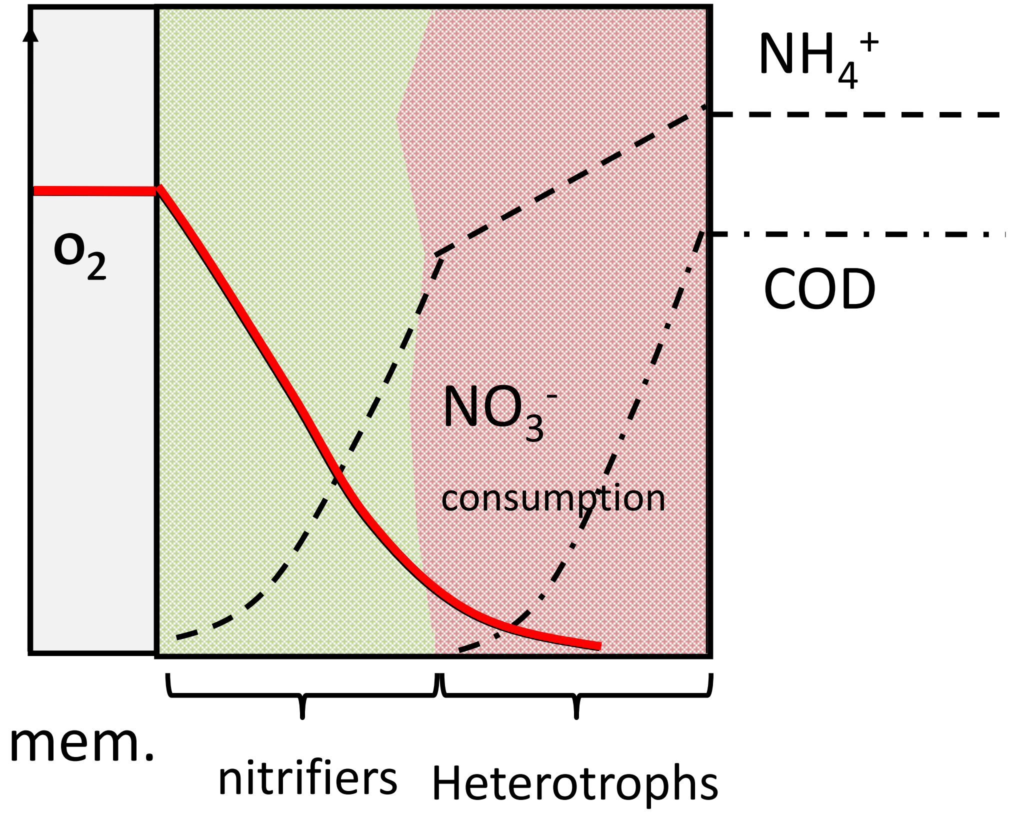
What is special about counter-diffusional biofilms?

1. Liquid diffusion layer retains “internal” substrate
2. Provides special niches
    - Example: nitrifying biofilm on O_2-supplying membrane

Conventional nitrifying biofilm



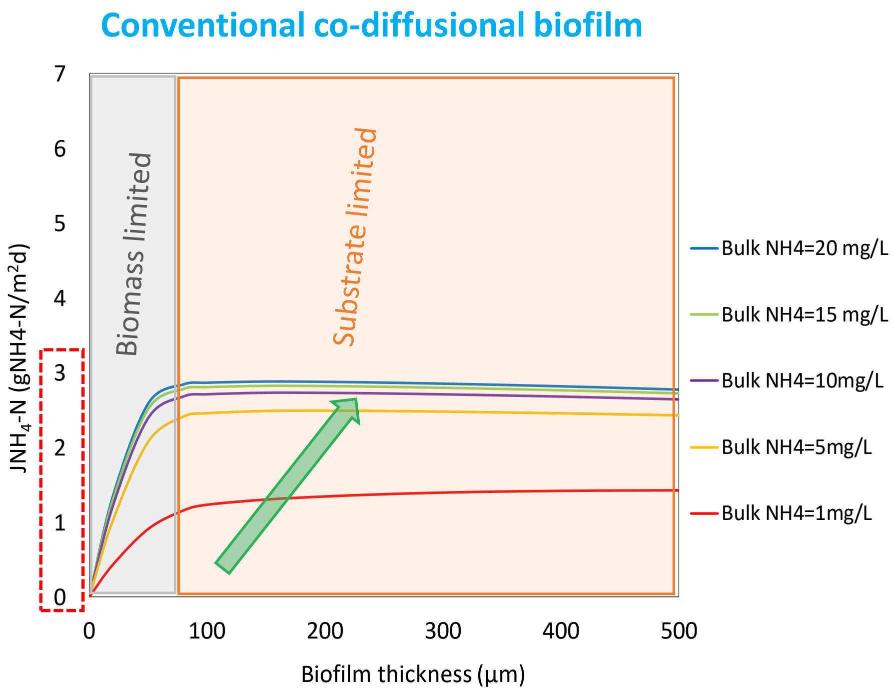
Counter-diffusion nitrifying biofilm

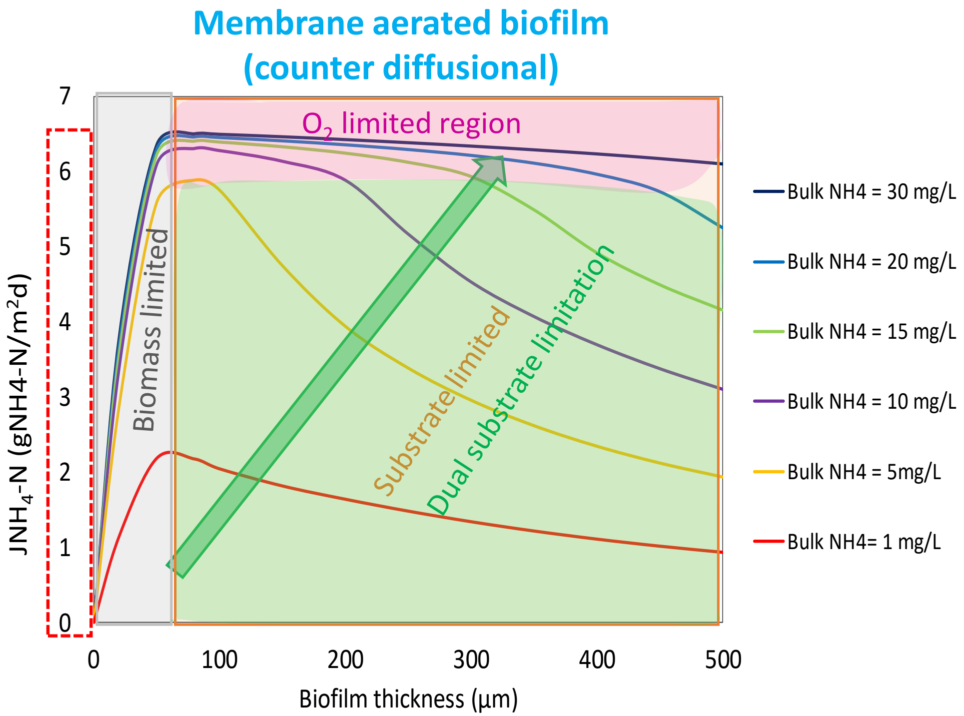


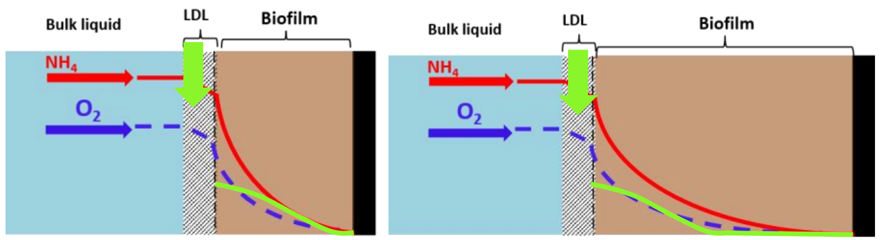
What is special about counter-diffusional biofilms?

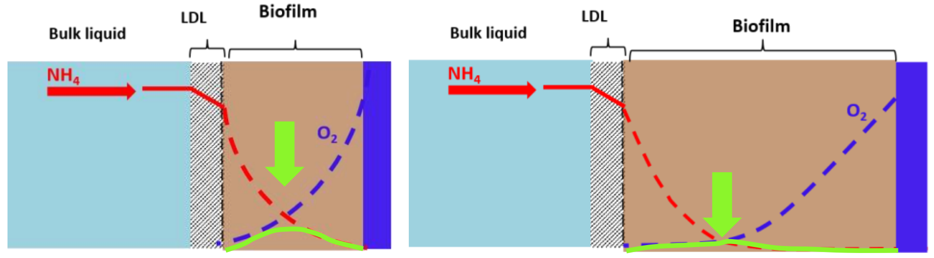
1. Liquid diffusion layer retains “internal” substrate
2. Provides special niches
   - Nitrifying bacteria
3. High fluxes, but highly sensitive to biofilm thicknesses

Effect of bulk NH_4-N and biofilm thickness









Summary: Counter-diffusional biofilms can be different!

1. Liquid diffusion layer retains substrates
2. Special niches
3. High fluxes, but highly sensitive to biofilm thicknesses

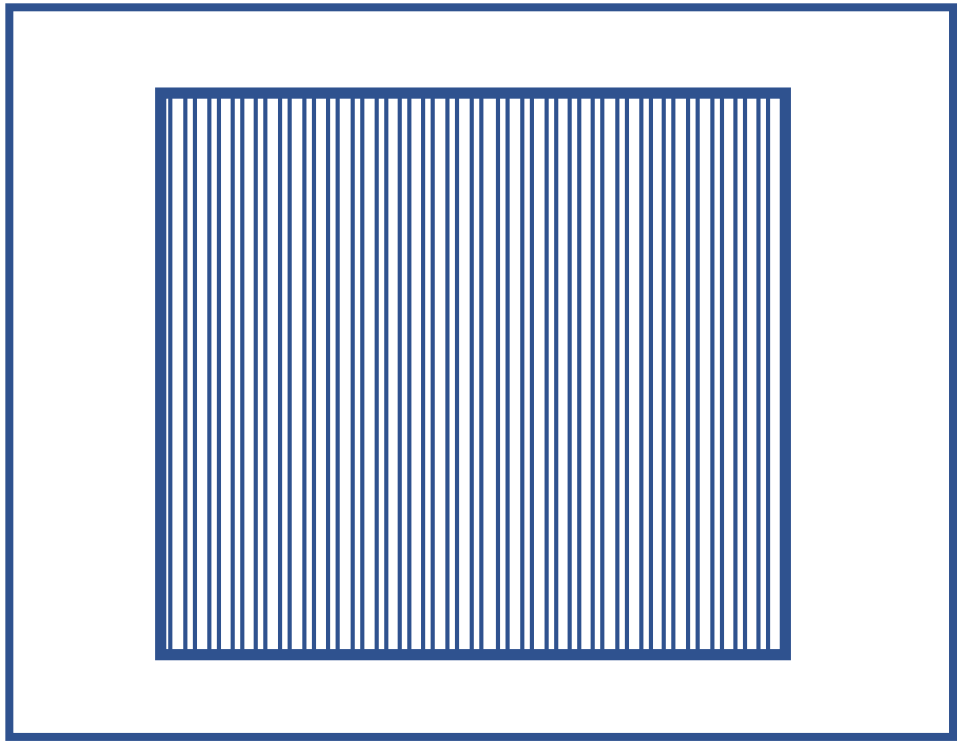
3. Research needs

Research Questions

- MABR reactor configurations
- MABR integration into treatment train
- MABR/Anammox
- MABR/BioP
- Greenhouse gas emissions
- MABR/micropollutants
- MABR predation
- MABR fungi

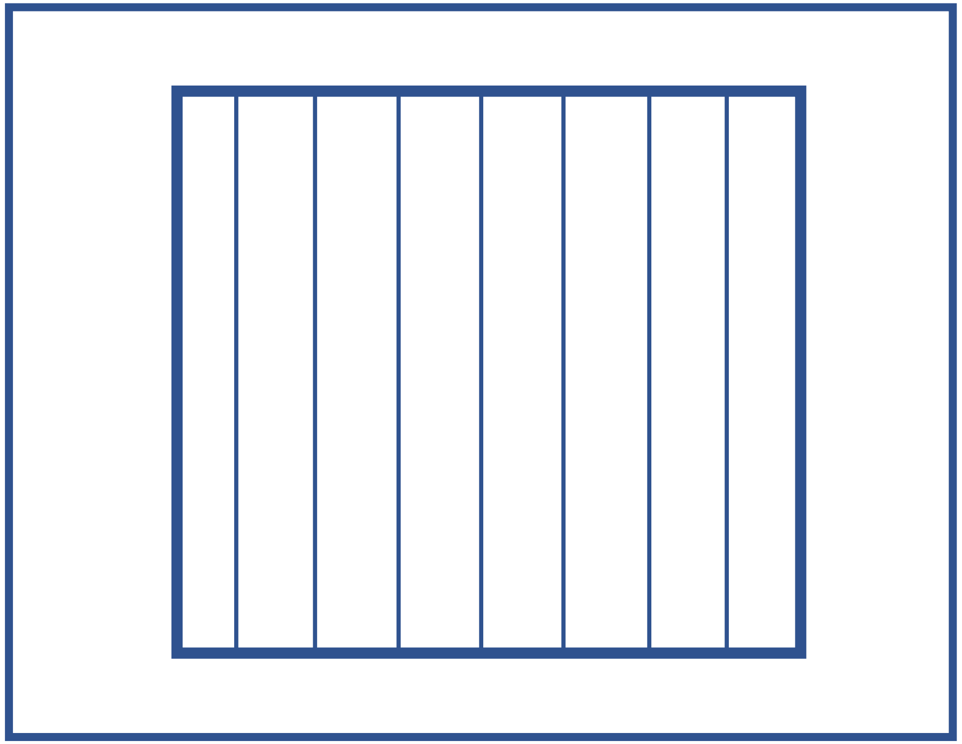
What is the optimal specific surface area *a*?

Higher *a* → *smaller V*



- Short circuiting
- High mixing energy required
- High biofouling potential

Lower *a*



- Higher cost "per m^2"
- Larger reactor volume
- Liquid contact with biofilm?

Module mixing regime

- Mechanical mixing?
- Pulsed bubbles?
  - Frequency?
  - Duration?
  - Intensity?

Well mixed vs. plug flow

- Well mixed - minimizes bulk COD and NH_4^+ concentrations
  - thinner biofilm
  - less mass transfer resistance for NH_4^+
  - Low nitrification rates due to low NH_4^+ concentrations
- Plug flow - high initial COD and NH_4^+, then decreasing values
  - Initially, thicker biofilm
  - Low nitrification rates due to high COD
  - Then higher nitrification rates, but less COD available for denitrification
  - At end, low nitrification rates due to low NH_4^+

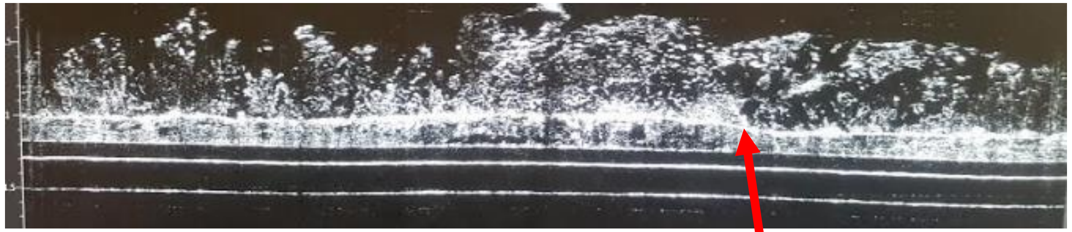
Biofilm control – how does it work?

- Reduce the biofilm uniformly?
- Slough all biofilm?
- Slough of some biofilm?
- Remove loose flocs?
- Remove outer heterotrophic layer?
- Remove AOB?

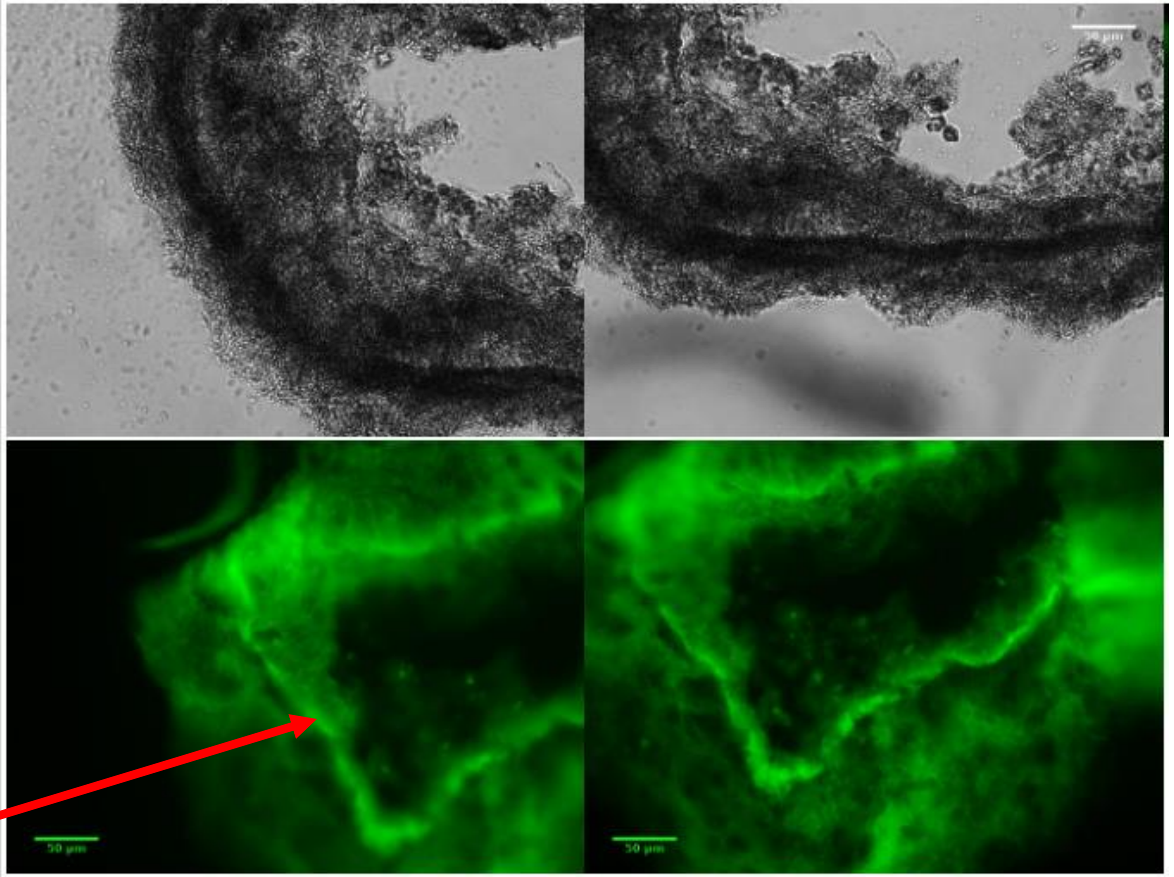
Interesting MABR observations

Interesting MABR observations – "band" of cells

Optical Coherence Tomography (OCT) images

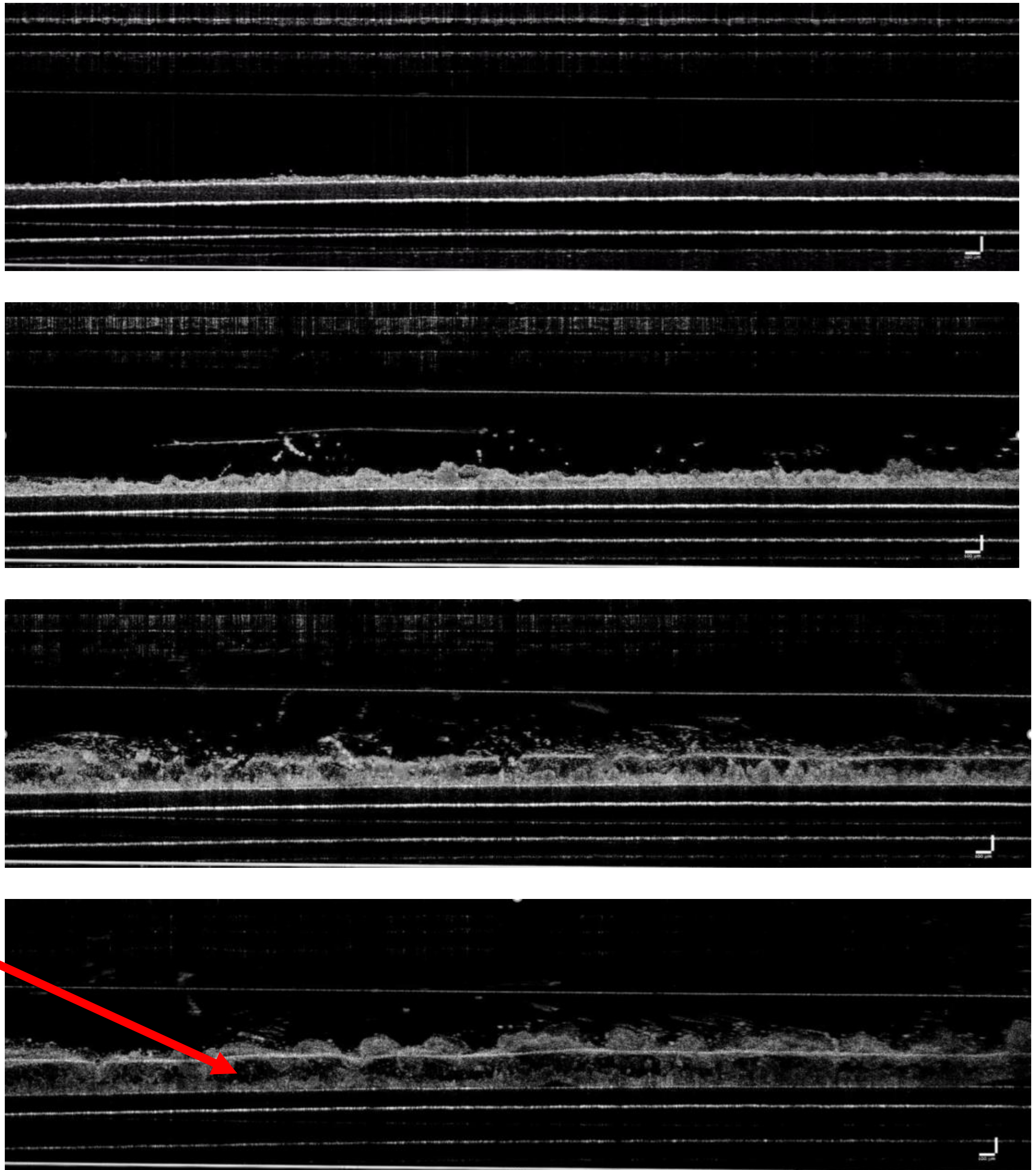


CLSM images



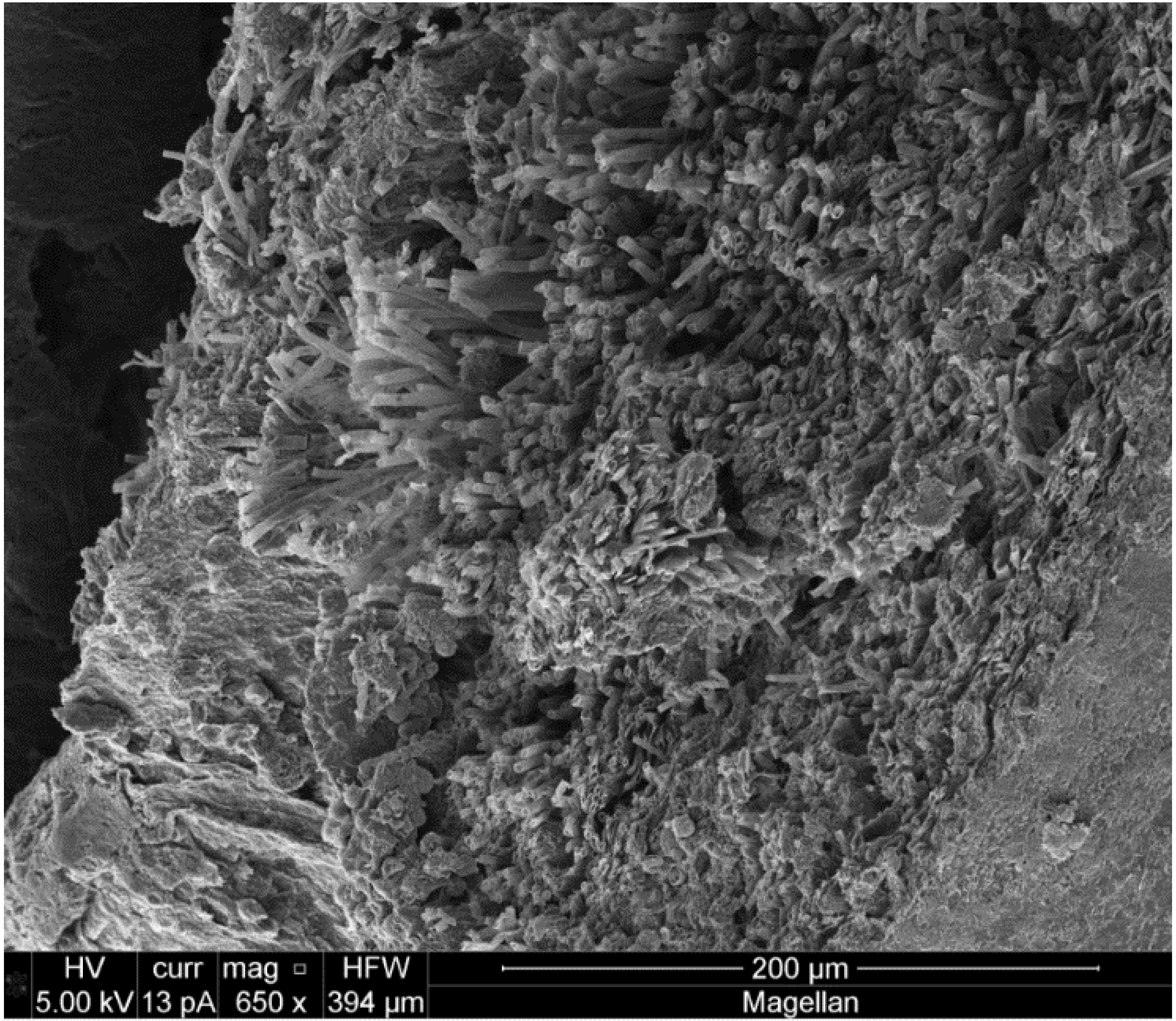
Band

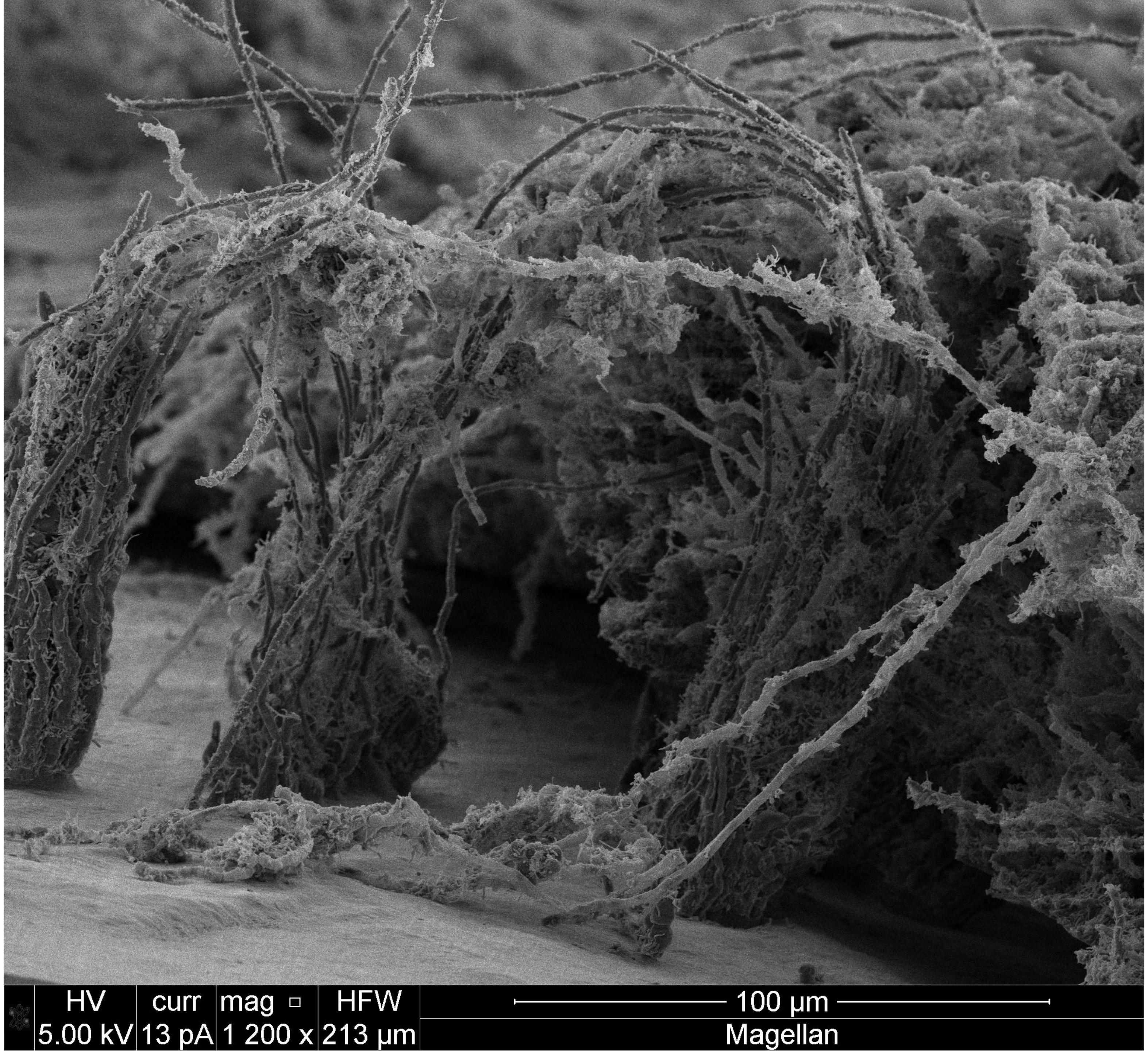
Interesting MABR observations - predation



Voids

Interesting MABR observations - filaments


HV
5.00 kV
curr
13 pA
mag □
650 x
HFW
394 µm
200 µm
Magellan


HV
5.00 kV
curr
13 pA
mag
1 200 x
HFW
213 µm
100 µm
Magellan

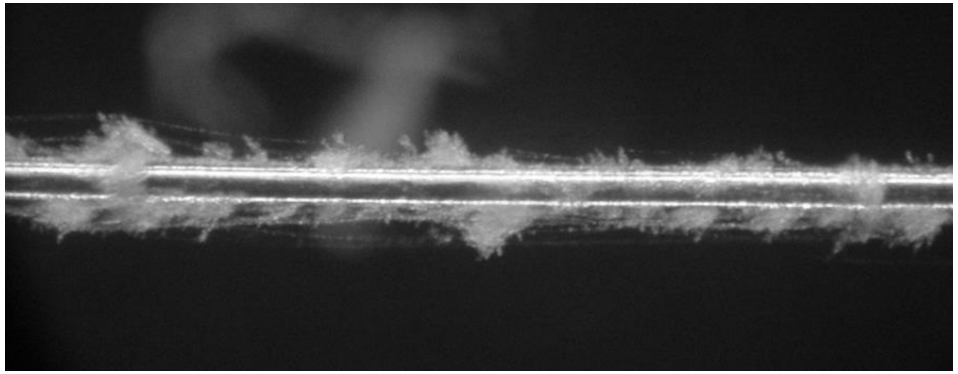
Fungal counter-diffusional biofilms?

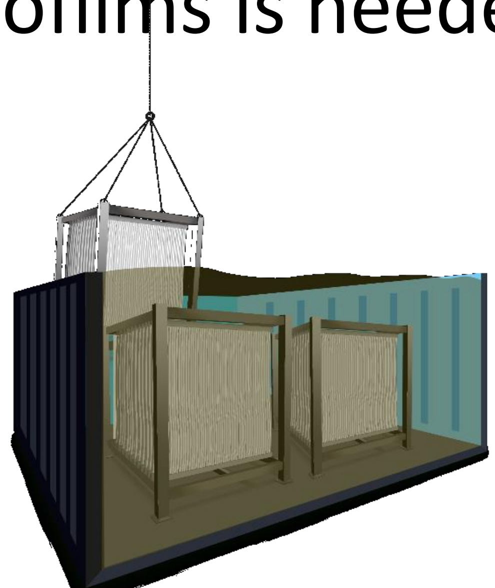
Kombucha SCOBY

4. Summary

Summary

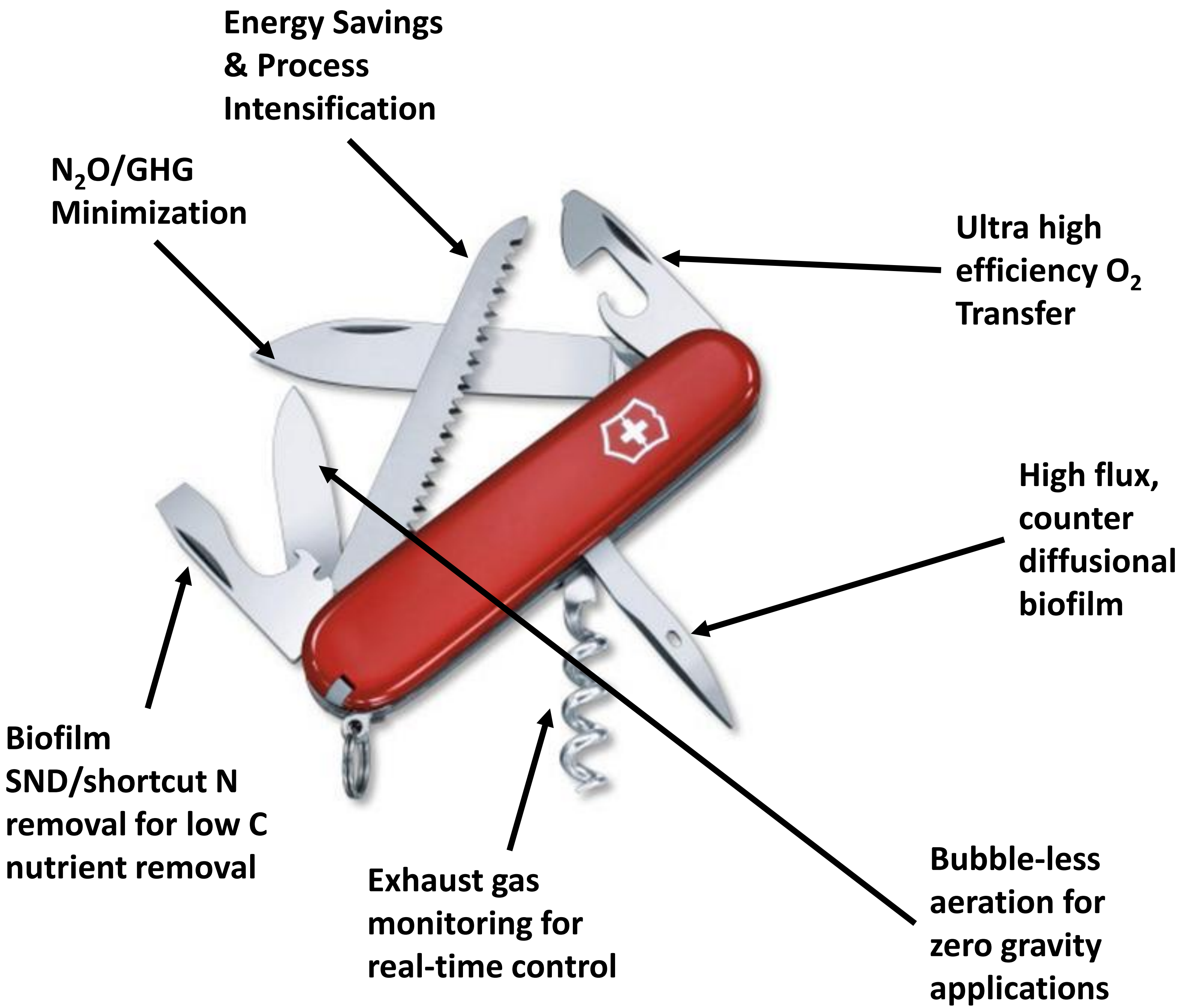
- MABRs can save significant space and energy
- Cost effective?
- May allow new processes
- MABR biofilms are different!
- A fundamental understanding of MABR biofilms is needed to maximize their success





Overview of Typical MABR Applications

Dwight Houweling, P.Eng., Ph.D.
IWA Biofilms 2020 MABR Workshop
Sunday, 6 December 2020



Which have emerged as key drivers?

Fluence:

Aspiral Wastewater Treatment System, Hubei China

Customer	Hubei Communication Investment Intelligent Detection Co., Ltd. (Hubei ITEST)
Project	Replacement of existing WWTP with highly compact Aspiral™ systems powered by MABR technology for Xiaogan highway service area in China. The location of the service area required a compact, fast and easy to install WWTP solution that can meet effluent requirements of China's Class 1A standards
Design Parameters	• Flow: 200 m^3/day (53,000 gpd) • Wastewater minimum temperature: 12.5˚C (54°F)
Solution	• **Pretreatment:** fine screen and selector tank • **Secondary treatment:** 2 Aspiral L4 packaged systems and a secondary clarifier • **Tertiary treatment:** media filters, disinfection units
Results	• Meets stringent effluent requirements of China's Class 1A standards • Energy consumption: 0.46 kWh/m^3 (total). Secondary treatment: 0.32 kWh/m^3 • Simplified operations & maintenance • Small physical footprint – Net 240 m^2 (2600 sq. ft), Gross 850 m^2 (9200 sq. ft) • Low noise and odor free

Parameters (mg/L)	pH	NH_4-N	COD	TN	TP	TSS	BOD
Influent	6 ~ 9	50	350	70	6	250	130
Effluent requirements	6 ~ 9	< 5	< 50	< 15	< 0.5	< 10	< 10
Effluent quality	**6.81**	**0.206**	**16**	**2.18**	**0.04**	**8**	**4.4**

Application #1: Package plants where MABR is at the heart of the secondary treatment step

Oxymem:

Our Solutions: OxyFILM application

OxyFILM - Unlocks the potential of fixed film:

- No MLSS – Only biofilm
- All steps in a single process – low footprint - SND
- New build plants is the main market
- High-rate pre-treatment
- Post aerobic/anaerobic polishing
- Modular package plant

OXYMEM
a DuPont brand

Application #2: Pure biofilm systems for high-rate pretreatment with SND

Oxymem:

Our Solutions: OxyFAS application

OxyFAS – Easy capacity increase

- Plant upgrades
- MABR – IFAS system. MABR works in conjunction with activated sludge.
- Easy gradual expansion possible
- ZERO footprint increase.
- No need to drain the tanks

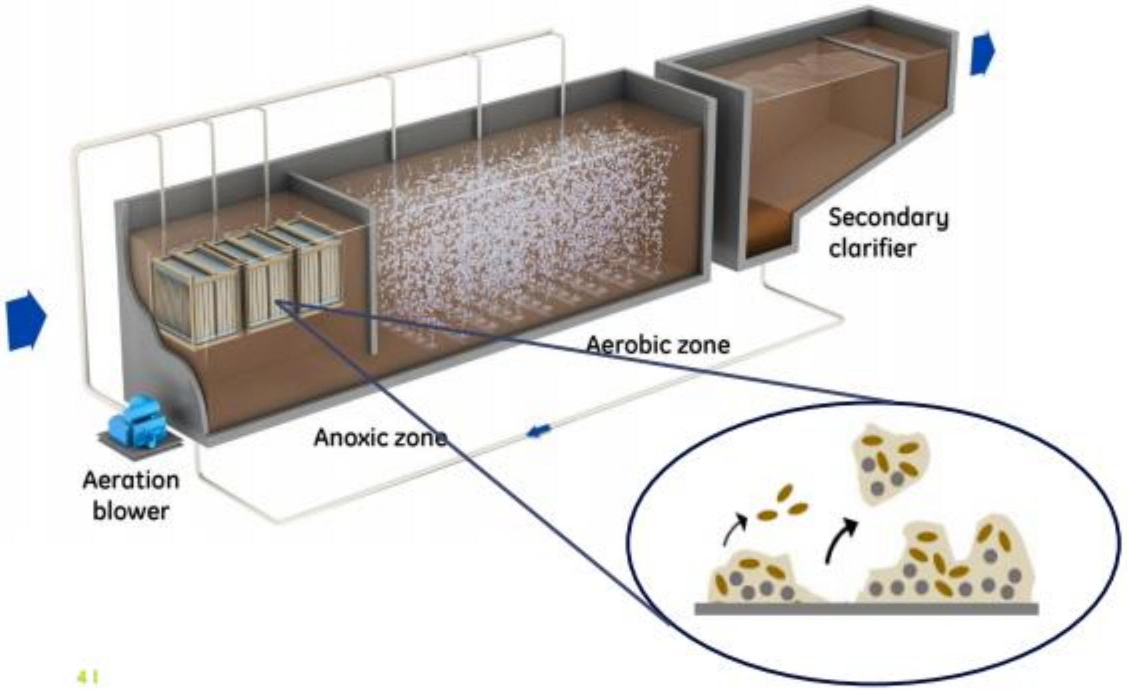
OXYMEM
a DuPont brand

Application #3: Hybrid biofilm/activated sludge systems for plant retrofits

ZeeLung:

process intensification by reducing aerobic SRT

how it works



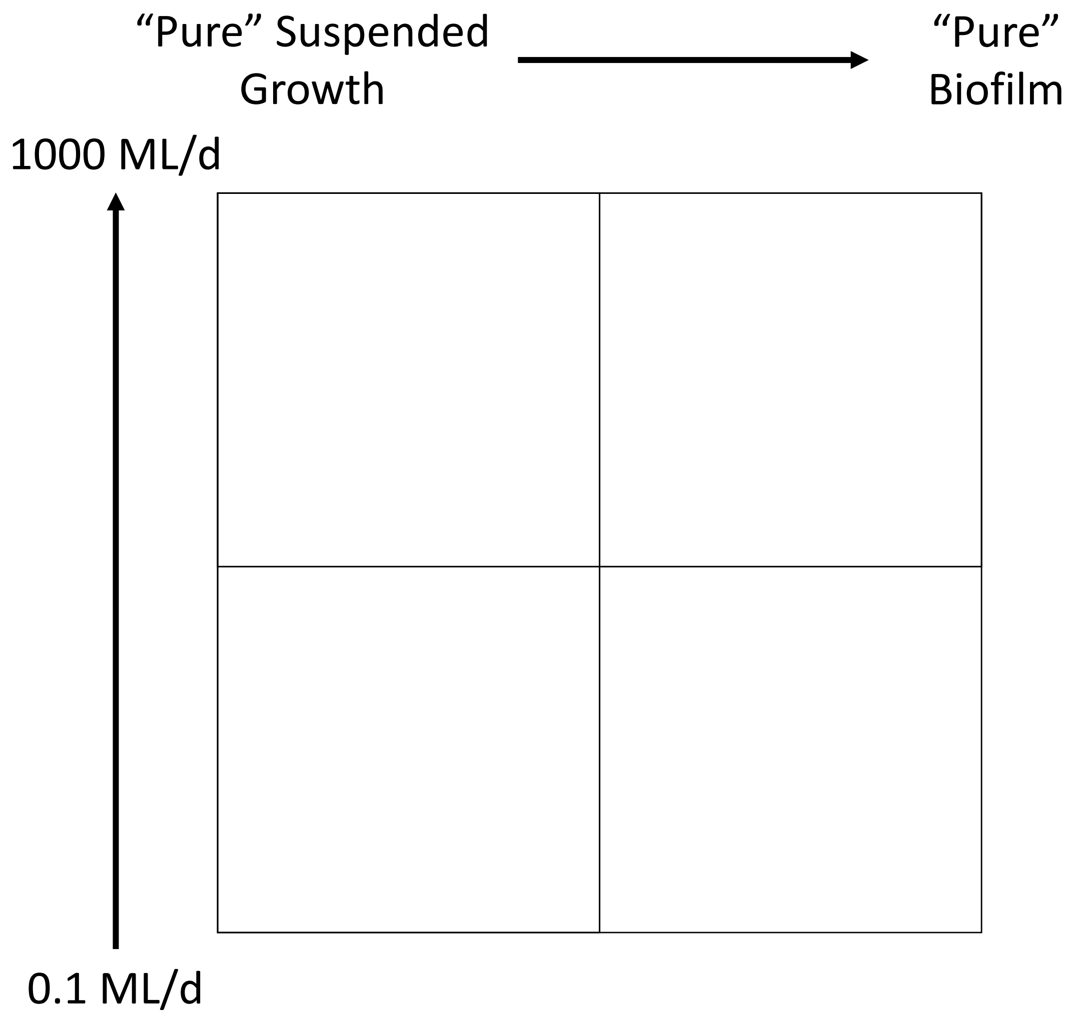
hybrid system with nitrification in biofilm and suspended biomass

ZeeLung cassettes at the "front" of the process remove 20-80% of ammonia

ZeeLung biofilm is rich in nitrifiers (10X more than suspended biomass)

biofilm nitrification provides seeding of nitrifiers and reduces load to suspended growth… enabling lower aerobic SRT

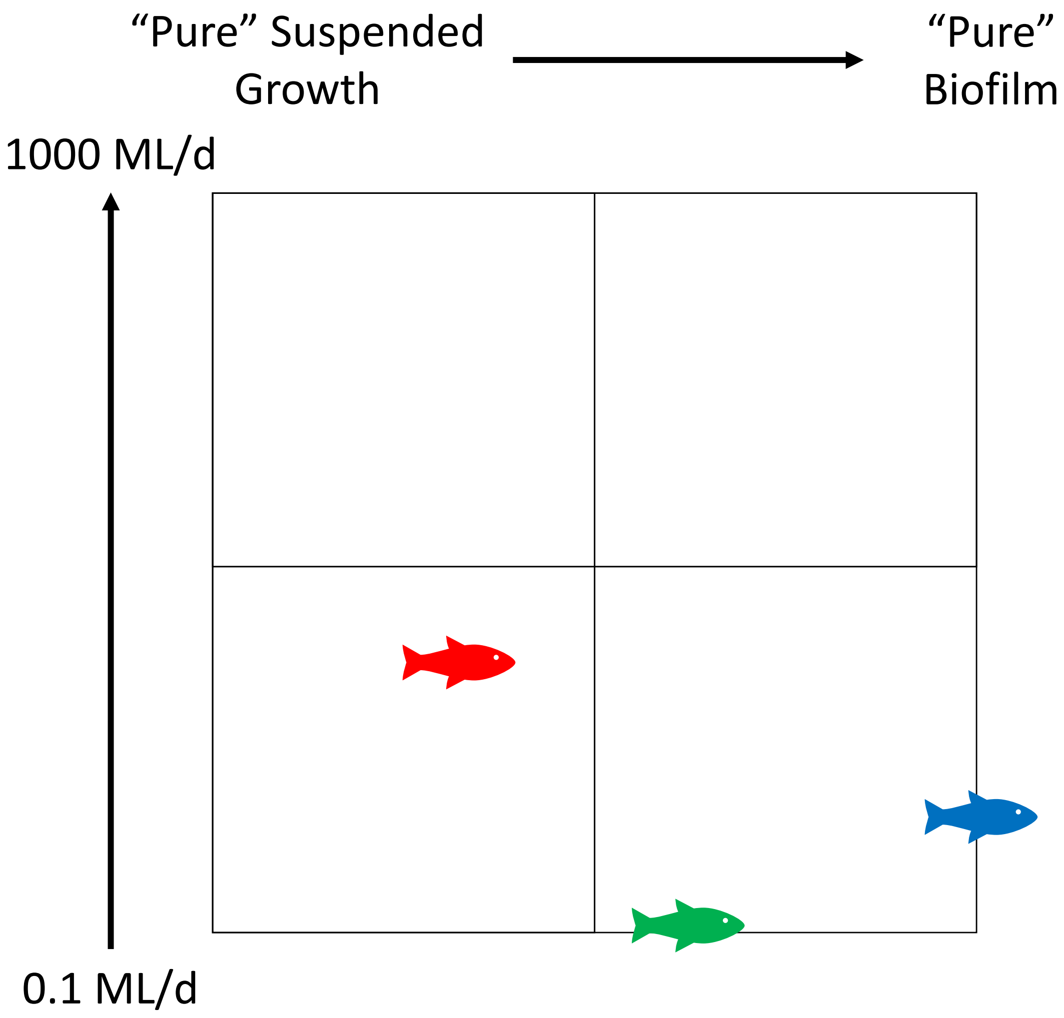
Application #3: Hybrid biofilm/activated sludge systems for plant retrofits



Three little fishes, where do they swim?

- Hybrid MABR/Activated Sludge
- “Pure” MABR
- MABR as part of “Package Plant”

Three little fishes, where do they swim?



- Hybrid MABR/Activated Sludge
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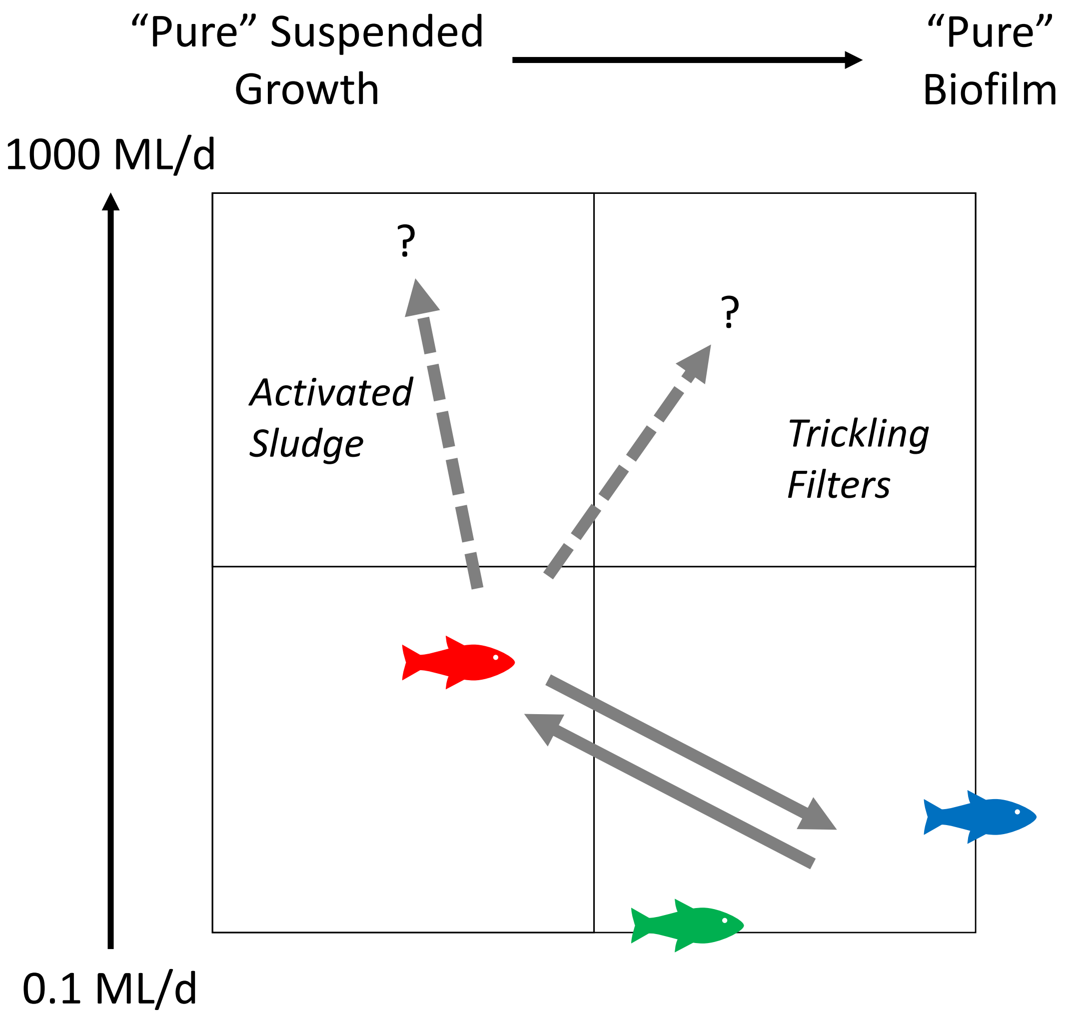
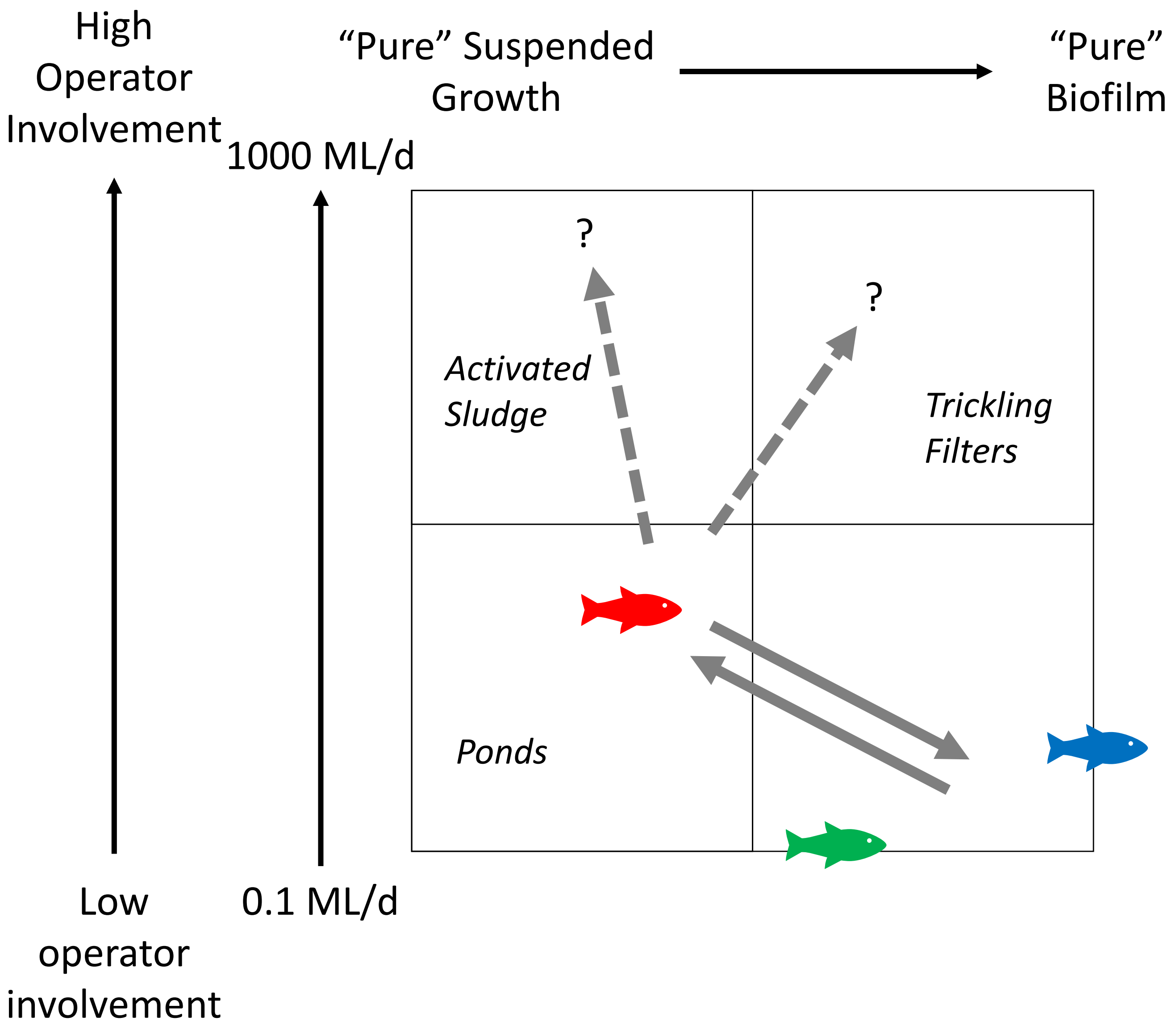


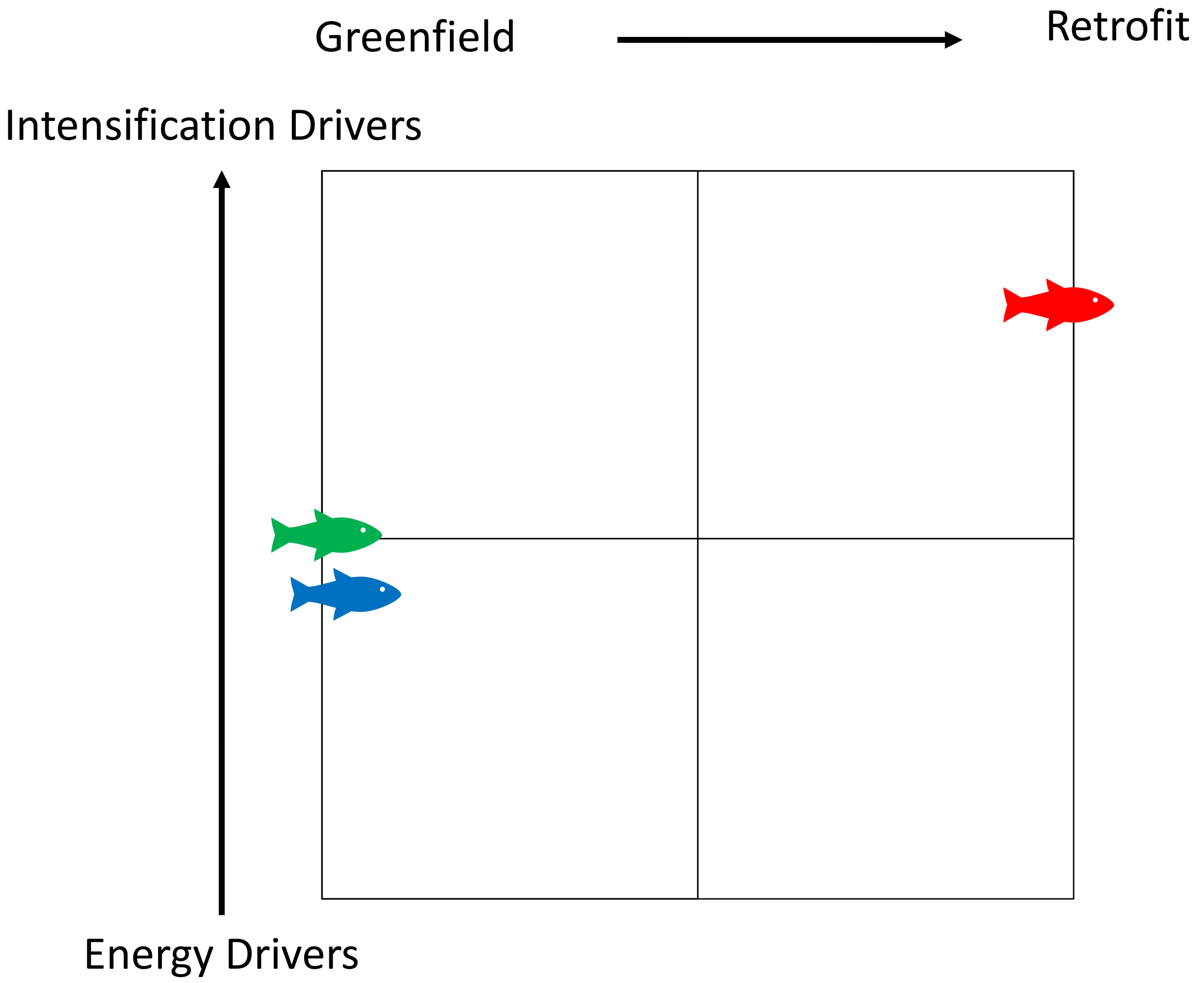
Pure biofilm at smaller flows?

Hybrid processes are for higher flows?



Biofilm technologies are inherently simpler and require lower operator involvement

Three little fishes, where do they swim?



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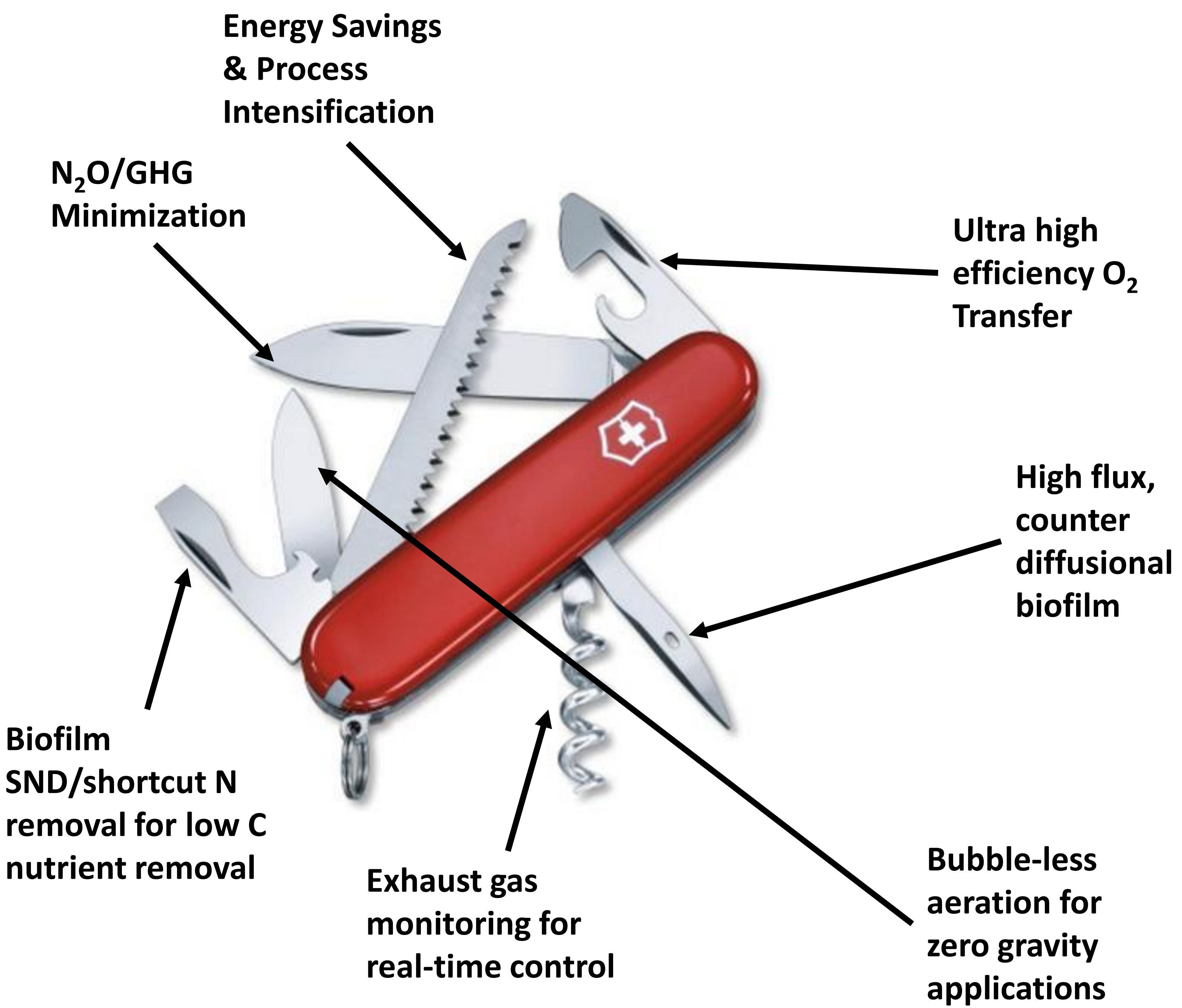

Which have emerged as key drivers?

Where will the little fishes go?