



**Biofilm Reactors:**  
**OPERATIONAL OVERVIEW AND APPLICATIONS FOR NUTRIENT  
REMOVAL**

**WWOA 46<sup>th</sup> Annual Conference  
October 11, 2012**

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# Acknowledgements

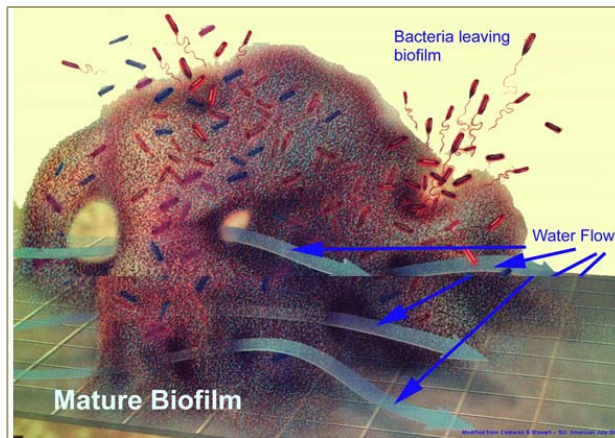


- Water Environment Federation (WEF) Manual of Practice (MOP) No. 29
  - Operation of Nutrient Removal Facilities
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    - Sarah Hubbell, Entex Technologies
    - Josh Boltz, Ph.D., P.E., BCEE, CH2M Hill

# Outline



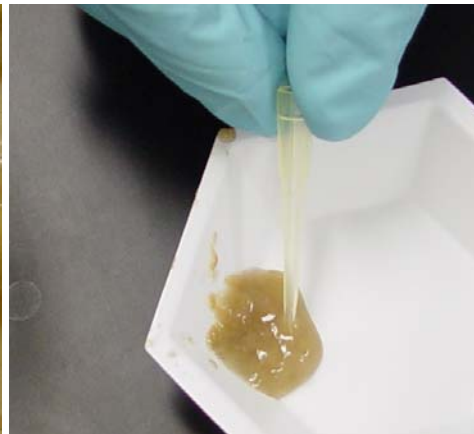
- What is a biofilm?
- Why is this important?
- Biofilm reactor controls
- Current applications
- Future direction



# What is a biofilm?



- “cells immobilized at a substratum and frequently embedded in an organic polymer matrix [EPS] of microbial origin” - Characklis and Marshall 1990
- Why biofilm and not fixed film???
  - Biofilm is scientifically accepted term
  - Better describes what the film is (i.e. biological film)

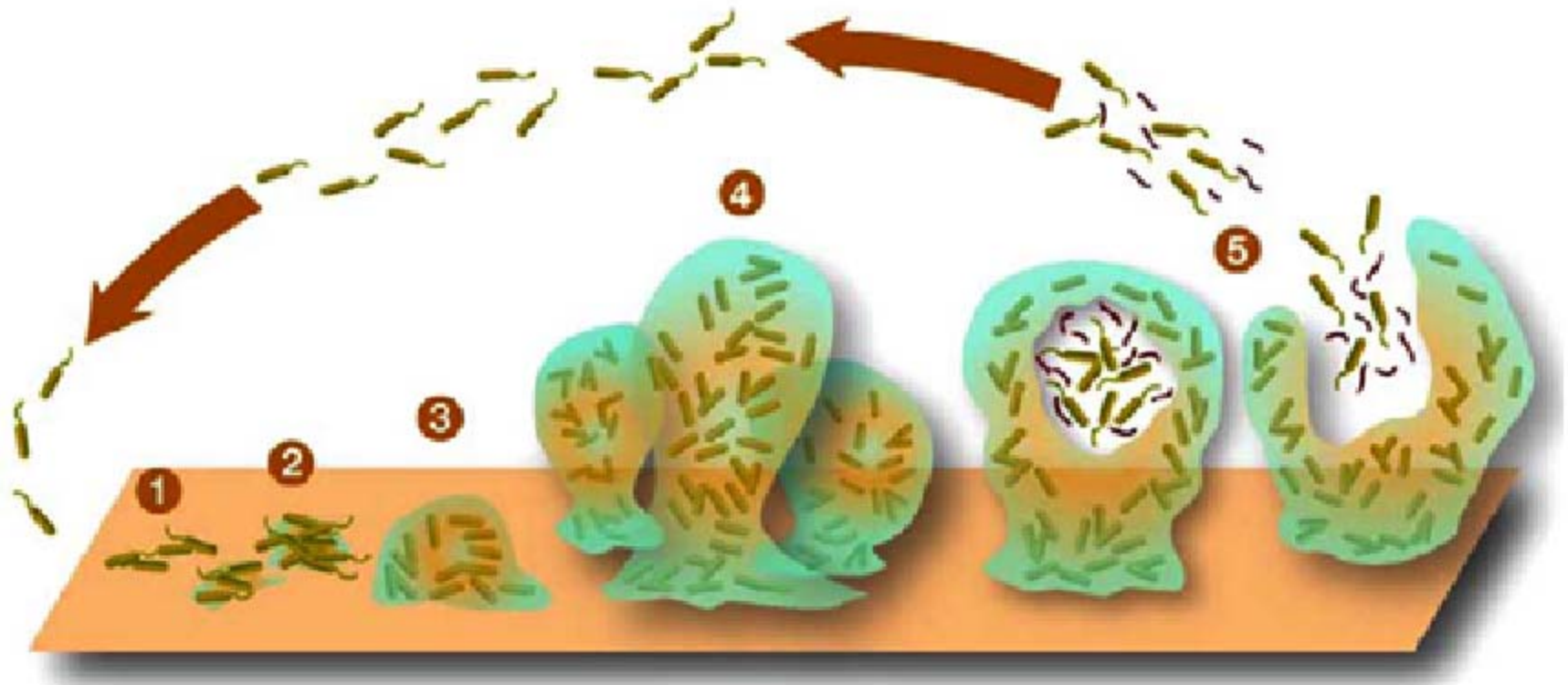
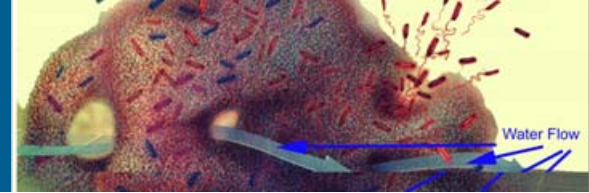


# What is a biofilm?



- Cell residence time independent of hydraulic residence time
- Increased volumetric activity
- Increased operational stability
- Increased resistance to toxic/inhibitory shock loads
- Different bioconversion processes in the same reactor

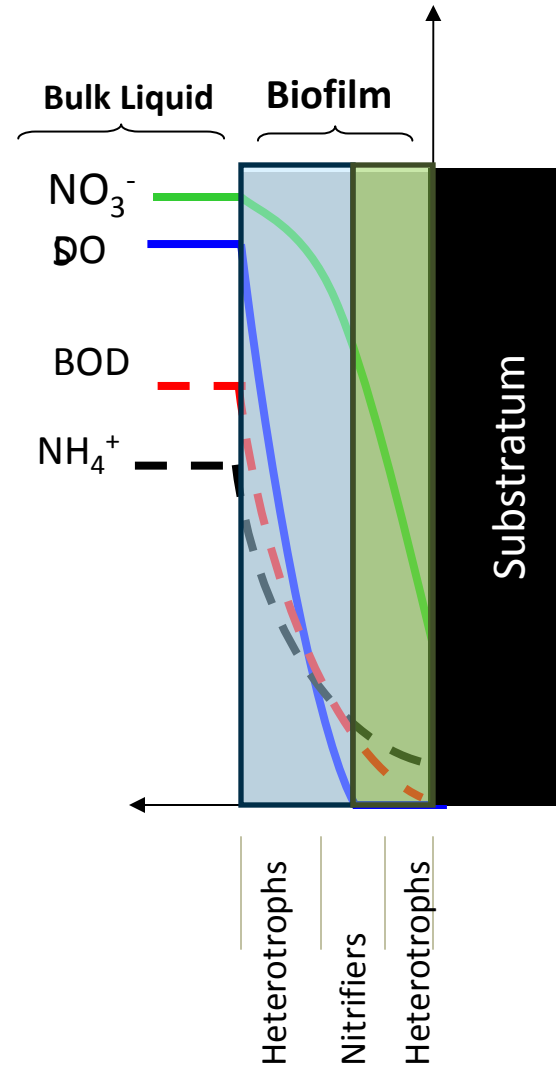
# Why is this important?



# Why is this important?

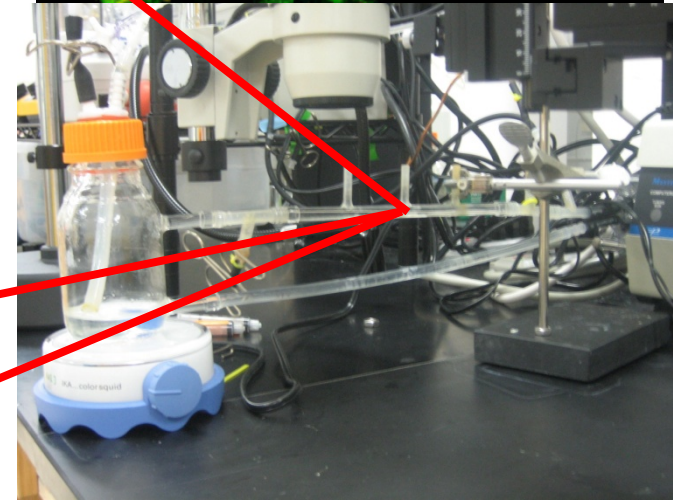
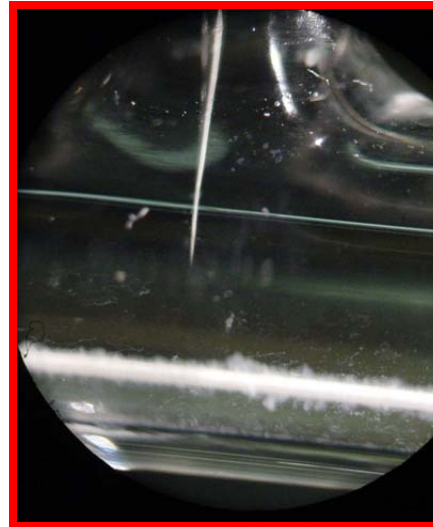
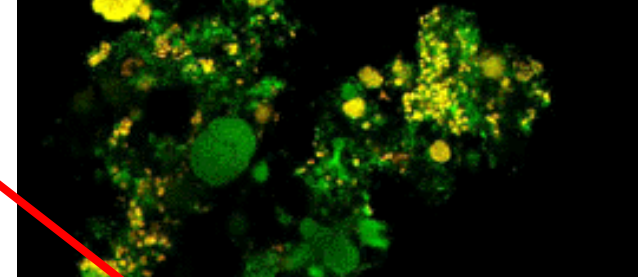
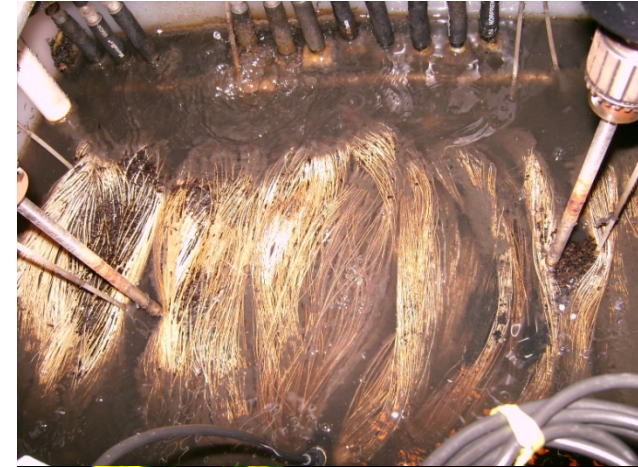
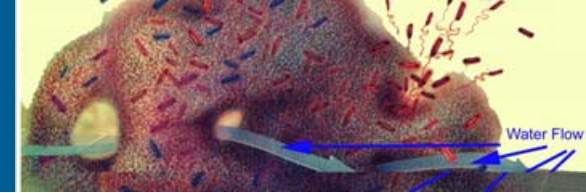


- What makes a biofilm different?
  - Not all cells see the same thing
  - Mass transfer constraints
- What controls a biofilm?
  - Rate of transfer into the biofilm
  - Thickness of biofilm
  - Activity in the biofilm



# Why is this important?

- Biofilm Research
  - Confirmed stratification of biofilm
    - Heterotrophs outside
    - AOB and NOB inside
  - Measured DO, ammonium, nitrite, and nitrate in a biofilm



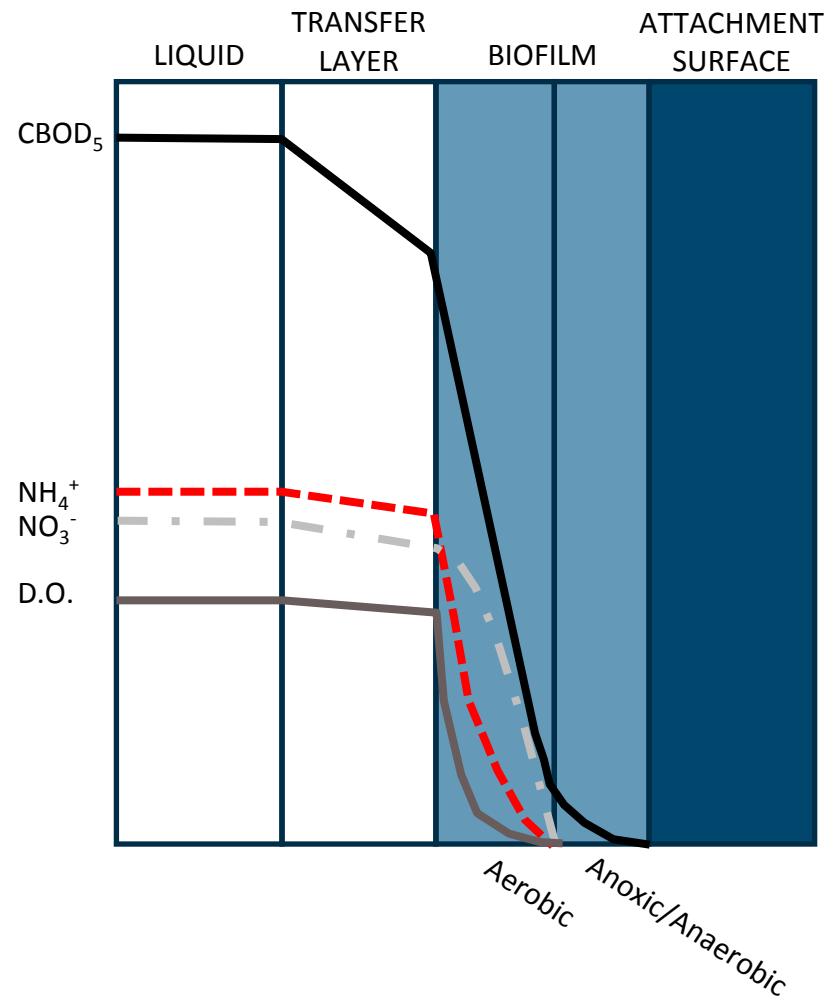
# Biofilm Operation



- How does stuff get into a biofilm?



Detroit Airport Fountain  
(Concourse A)



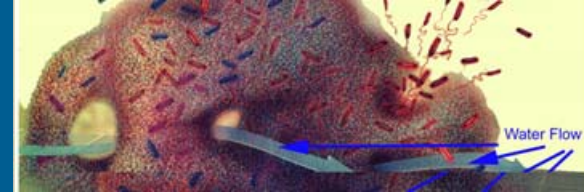
# Biofilm Operation



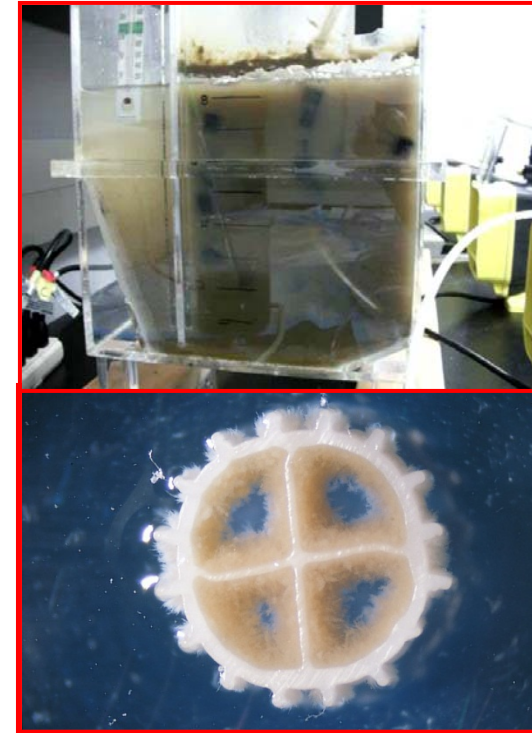
- Controlling nitrification
  - Gets stuff into the biofilm “faster”
    - Decrease “smooth” flow layer thickness
    - Increase liquid dissolved oxygen concentration
  - Prevent excess biofilm thickness and sloughing
    - Consistent, gentle scouring of biofilm
    - Not too thick, not too thin, but just right



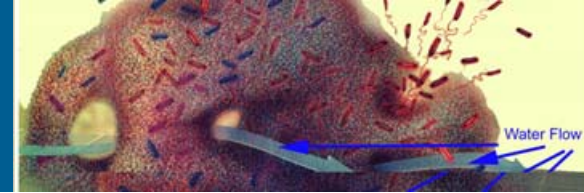
# Biofilm Operation



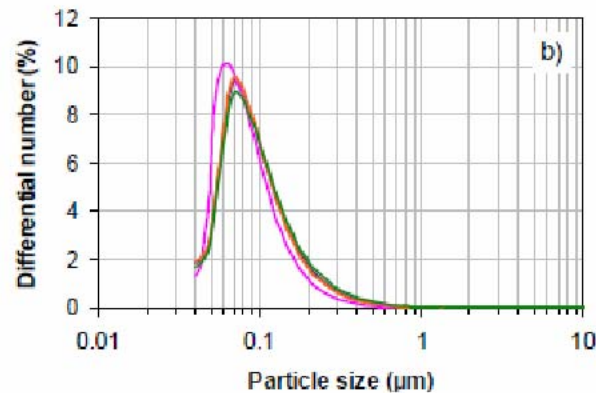
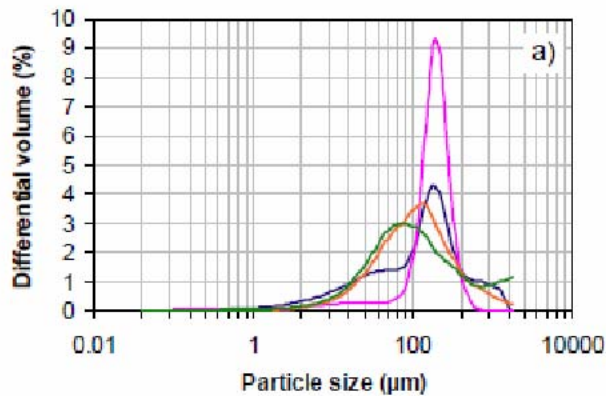
- What are our “knobs” to turn?
  - Liquid velocity
    - Aeration (MBBR, IFAS)
    - Mechanical mixing (MBBR)
    - Backwashing (BAF)
    - Flushing water (Trickling Filter)
    - Rotation speed (RBC)
  - Increase DO concentration
    - Increases with liquid velocity increase



# Biofilm Operation



- Solids settleability
  - Small particle size = poor bioflocculation
  - Options:
    - Downstream flocculation (biological or chemical)
    - Downstream filtration



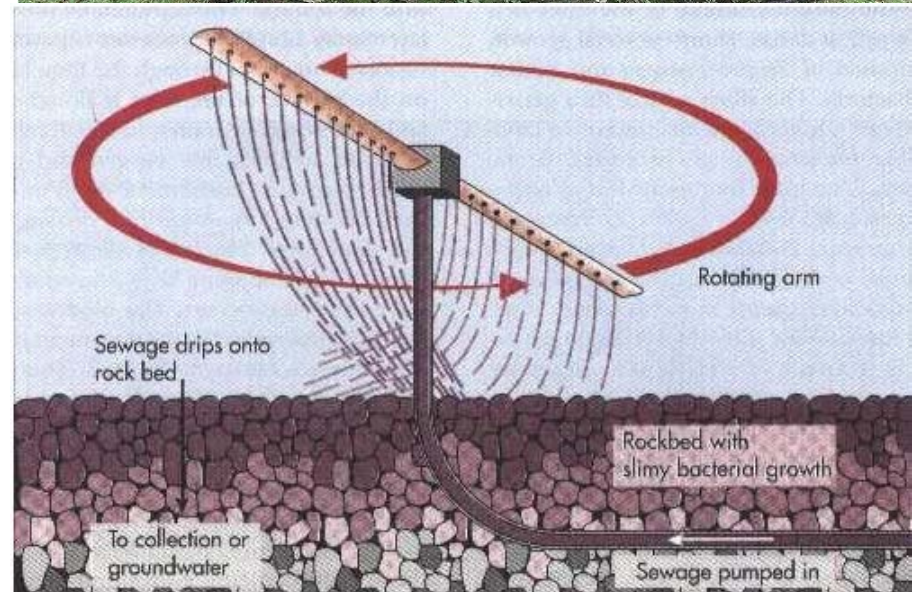
— Raw water — Salsnes filter — MBBR — Membrane tank

— Raw water — Salsnes filter — MBBR — Membrane tank



# Technologies

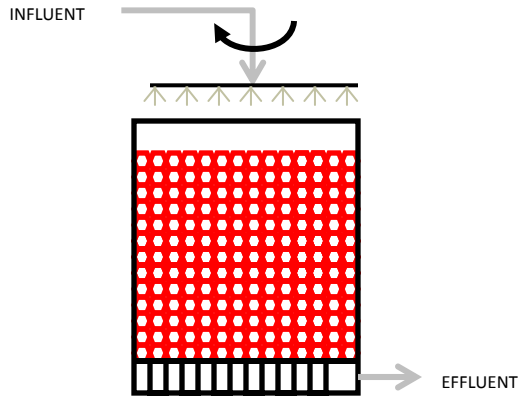
- Oldest applications in wastewater treatment
  - Trickling filter (1890s)
  - Attachment to walls observed to increase removal in activated sludge (1960s)
- Aerobic processes
- Low-tech, easy to operate



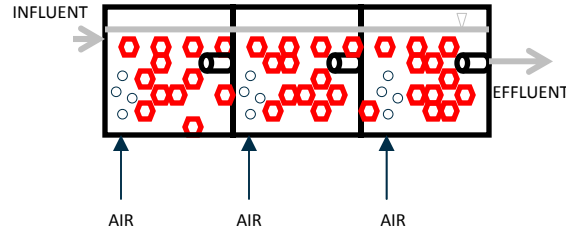
# Technologies



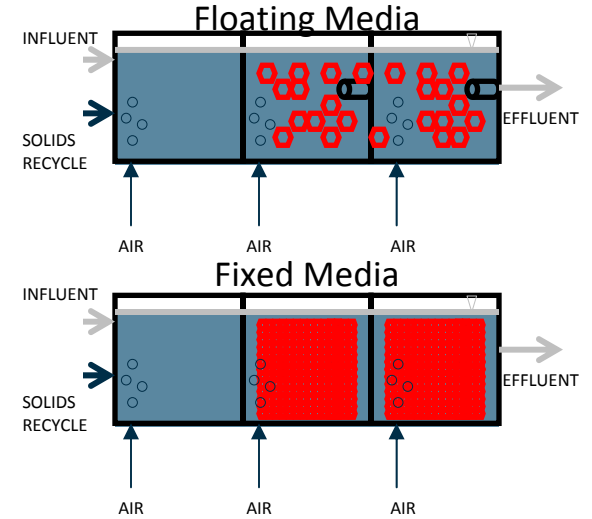
### A. TRICKLING FILTER



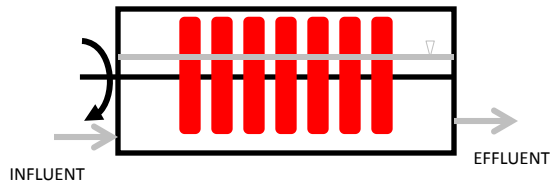
### B. MOVING BED BIOFILM REACTOR (MBBR)



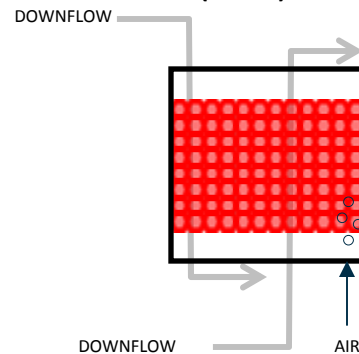
### C. INTEGRATED FIXED FILM ACTIVATED SLUDGE (IFAS)



### D. ROTATING BIOLOGICAL CONTACTOR (RBC)



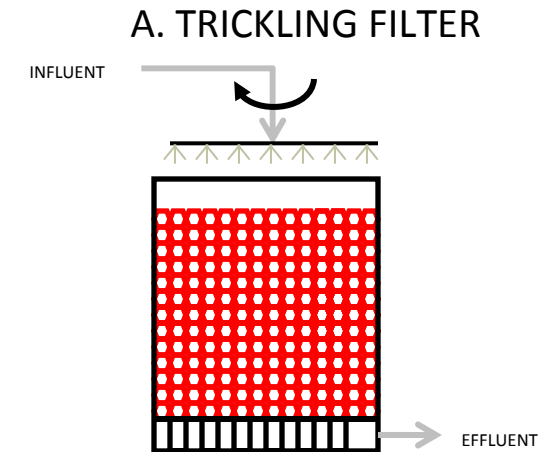
### E. BIOLOGICALLY ACTIVE FILTER (BAF)



# Technologies – Trickling Filter



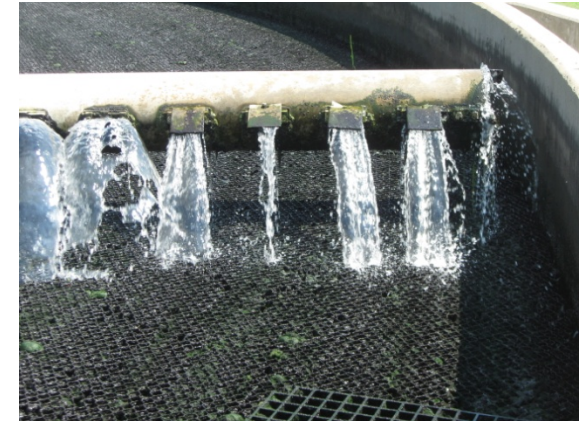
- Biofilm support
  - Rocks
  - Cross flow media
- Main Controls
  - Recirculation flow rate
    - Increase recirculation flow increases liquid velocity *and* oxygen concentration
  - Forced ventilation
    - Oxygen supply
    - Temperature control



# Key Components



- Spülkraft (SK) Value
  - Measure of the *intensity* of water application
  - More intense application → higher SK value → thinner film and fewer flies
  - More intense flow → less frequent application
- Wetting efficiency
  - Frequency of water application
  - Too frequent → odor issues
  - Not frequent enough → fly issues
  - Provide sufficient recovery time for biofilm without drying out
- How can these parameters be controlled?
  - Number of arms
  - Rotational speed
  - Recirculation pumping rate



Low intensity water application (splashing)

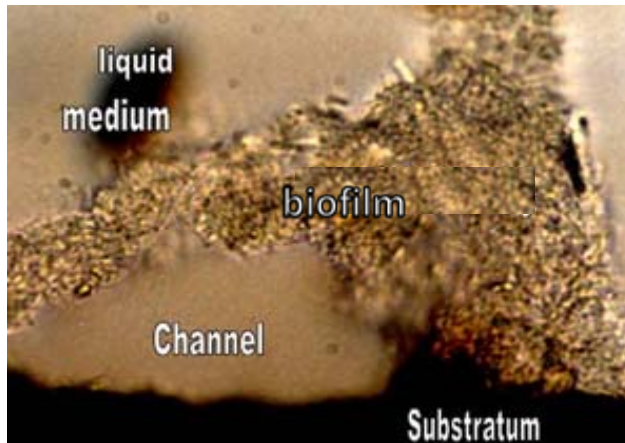


High intensity water application (dousing)

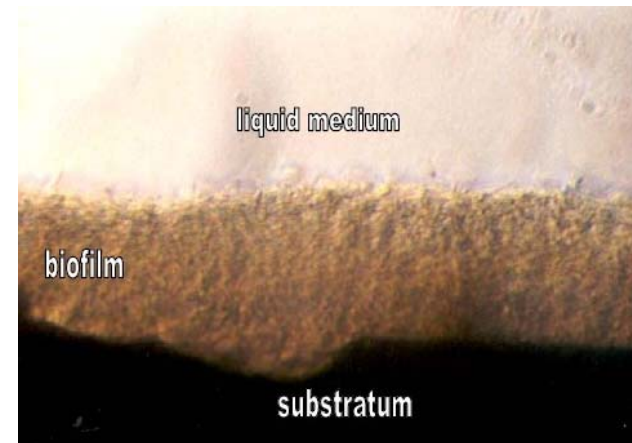
# Spülkraft (SK) Value



- SK value
  - $SK = \text{THL} / (N_a * \omega_d)$
  - THL = Total Hydraulic Load (influent plus recirculation)
  - $N_a$  = Number of arms
  - $\omega_d$  = Rotational speed
- Increased SK → More Intense Application → Healthier biofilm



Lower SK → Less Healthy Biofilm



Higher SK → Healthier Biofilm

# Number of Arms



## Two Arms

- Increased application intensity
- Requires faster rotation speed
- More time between application



## Four Arms

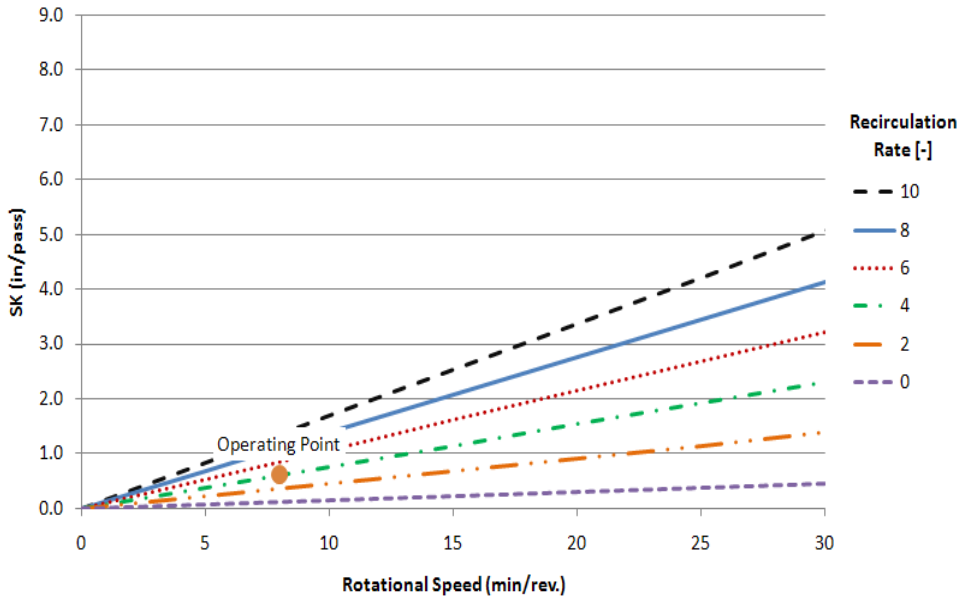
- Decreased application intensity
- Requires slower rotation speed
- Less time between application

# Example

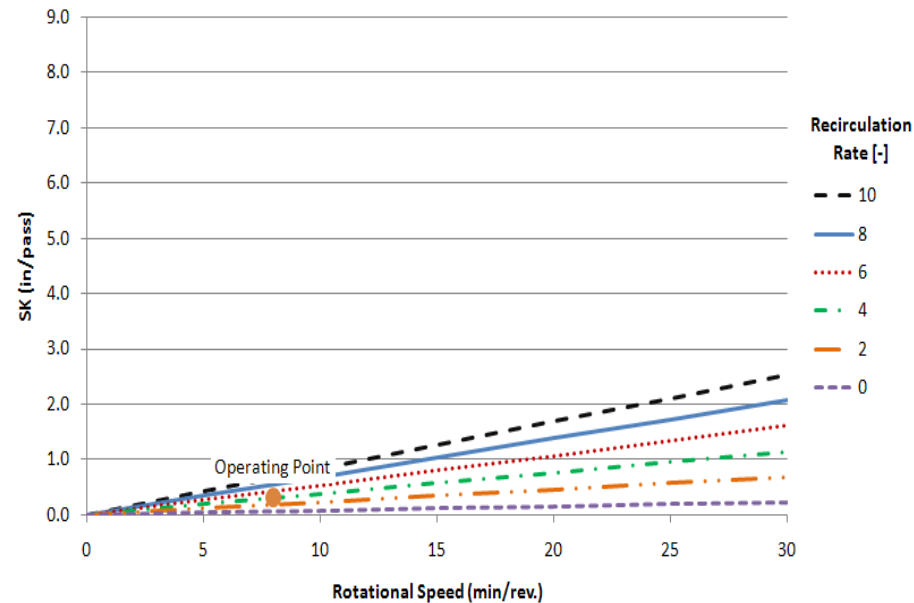


- Trickling filter operation
- $Q_{in} = 3.3$  MGD
- $Q_r/Q_{in} = 3$
- Rotational speed = 4 min/rev.

## 2 ARMS



## 4 ARMS



# Where are we Operating?



Innovative approaches  
Practical results  
Outstanding service

PROJECT NAME: DWU Tricking Filters Design and Operation

DATE: December 2010

## Dallas Plant Parameters

Total Flow	40 MGD
Primary Effluent BOD	85 mg/L
Number of Ticking Filters	12
Number of Arms per Filter	4 [-]

## Notes:

Total influent flow  
Dallas Plant primary effluent  
Number of trickling filters following decommissioning  
Number of distributor arms per trickling filter

## Operational Parameters

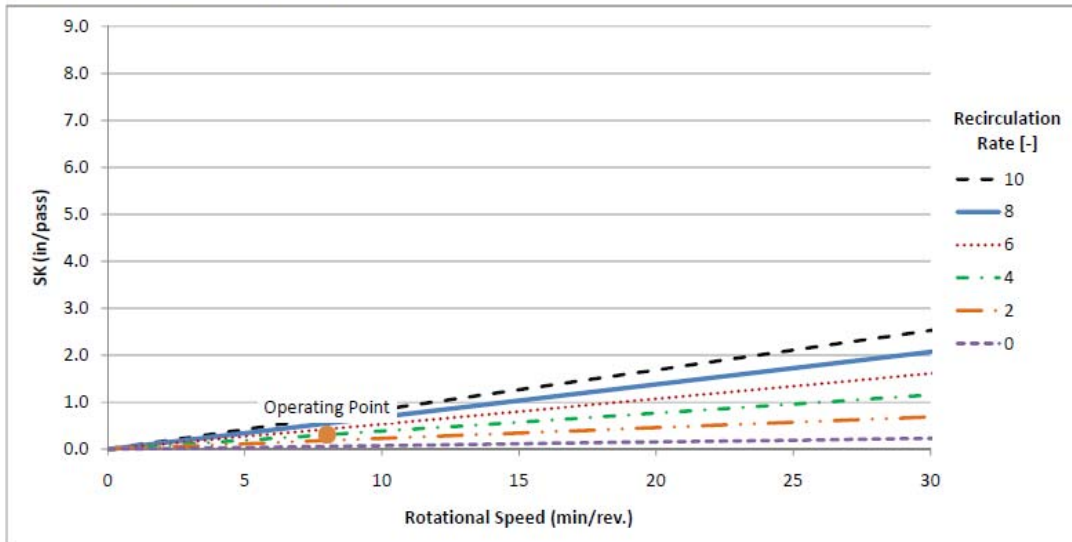
Recirculation rate	4 [-]
Rotational speed	8 min/rev

Ratio of recirculation flow to influent flow,  $Q_R/Q_{in}$   
Rotational speed of distributor arms

## Process Performance

Removal Efficiency	70.2%
Effluent BOD	25.3 mg/L
SK Value	0.307 in/pass
SK Ideal Range	1 to 9 in/pass
Organic Loading Rate	12.2 lbs/1,000 cf-day
Organic Loading Range	25 to 75 lbs/1,000 cf-day

BOD removal in Dallas Plant trickling filters  
Effluent BOD from Dallas Plant trickling filters  
Spulkraft number; measure of operating dosing rate intensity  
BOD loading to Dallas Plant trickling filters



# Key to Success with Trickling Filters

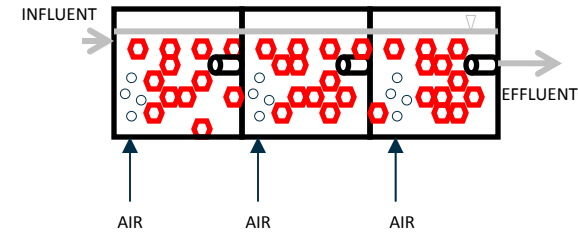


- Find the Right Balance
  - Process and hydraulic performance
    - Loading rates
    - **Recirculation rate**
  - Biofilm thickness and health
    - Rotational speed
    - **Recirculation rate**
    - **Number of distributor arms**
  - Odor and fly control
    - **Rotational speed**
    - **Number of distributor arms**

# Technologies - MBBR

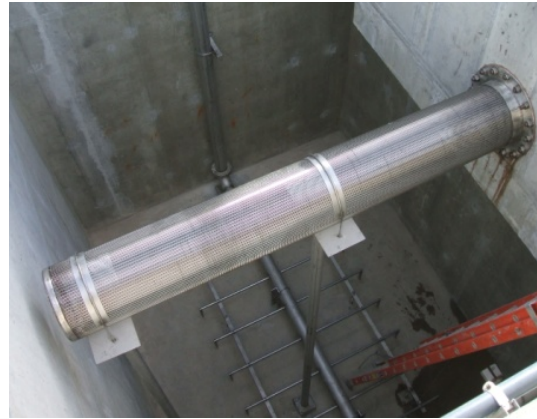
- Moving Bed Biofilm Reactor
- Floating media in reactor
- **NO suspended growth recycle**
- Compact process
- Multi-stage process
  - L:W close to 1:1
  - Later stages: low concentrations
  - Select for “bugs” that thrive under a set of conditions
- Main controls
  - Aeration supply rate

## B. MOVING BED BIOFILM REACTOR (MBBR)



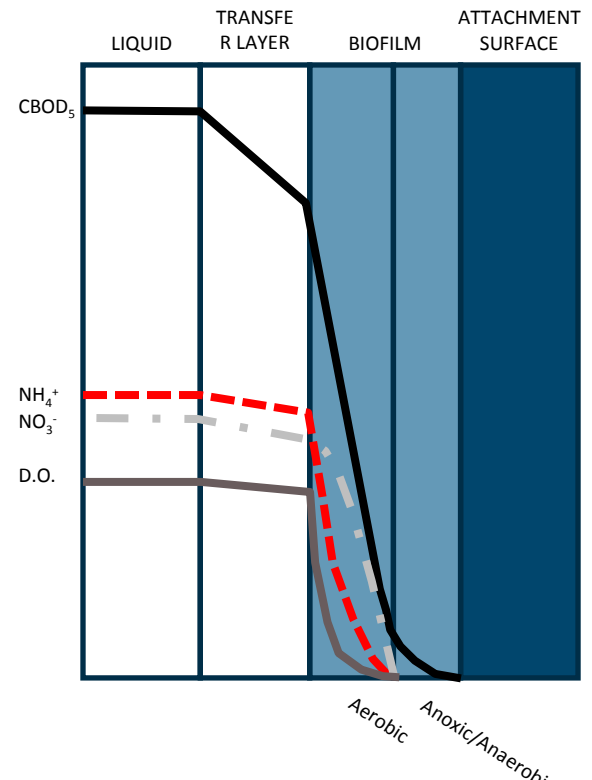
# Technologies - MBBR

- Media retention is key
- Retention Sieves
  - Effluent cylinders
  - Drains
  - Overflows
  - Everywhere...
- Influent screening is critical
  - With primary clarifiers: 6 mm
  - Without primary clarifiers: 3 mm



# Technologies - MBBR

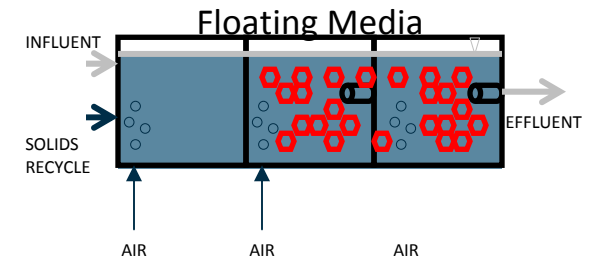
- What can we control?
  - Biomass concentration
    - Biofilm thickness: self regulating
    - Media volume: typically set during design
    - Not a lot of control
  - DO concentration
    - Medium bubble aeration
    - Operate at higher DO 4-6 mg/L)



# Technologies - IFAS

- IFAS

- First application – 1943
- Gained momentum in late 1990s
- Main driver: increased nitrification in same tank volume



# Technologies - IFAS

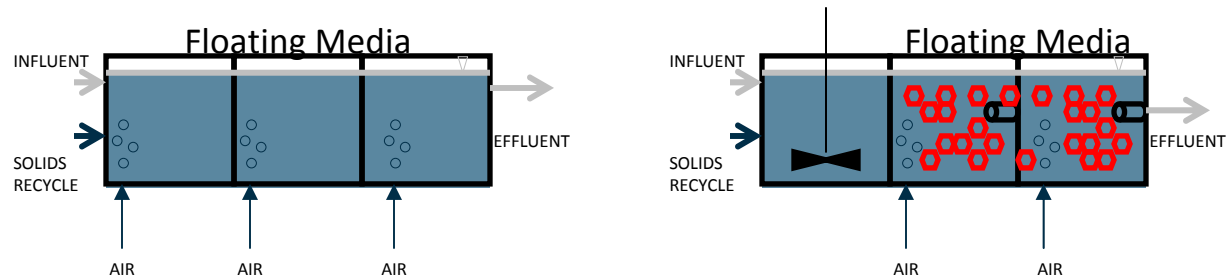
- Floating media
  - Same control as MBBR for the biofilm
  - Same control as AS for suspended growth
- Fixed media
  - “Clumping” risk
  - One big mass of biomass
  - No diffusion to center
  - Periodic sparging is key
    - Fine bubble aeration
    - Coarse bubble scouring
- What can we control?
  - Aeration supply rate!



# Biofilm and Future Nutrient Limits



- What role can biofilms play?
  - Lower P limit leads to larger chemical demand
  - Maximize biological phosphorus removal
    - More existing basin available for selector volume
    - Incorporate selector volume for bio-p and denitrification
    - No new tankage



# Biofilm and Future Nutrient Limits



- What role can biofilms play?
  - Clarifier limitation
    - Increase biomass without increasing MLSS
    - Higher biological activity, same solids loading to clarifier
  - Wet weather
    - High peak flows can “washout” suspended growth
    - Biofilms are “stuck”
    - High peak facilities may benefit from biofilm process

# Questions?



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