An Innovative Membrane Bioreactor Process for Achieving Sustainable Advanced Wastewater Treatment

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Sustainable Solutions Research

- Sustainability – sustainable development is continual improvement in one or more of the three domains of sustainability without causing degradation in any one of them either now or in the future:
  - Economic
  - Environmental
  - Societal

- "Our solution to a problem must not only solve the problem at hand, but it also must not create a new problem as a result. As stated earlier, sustainability must be our 'true north'." – Paul Anastas, ORD Assistant Administrator

Background

- **Membrane Bioreactors (MBR) (< 1 µm pore size)**
  - **Emerging technology for sustainability in wastewater treatment**
  - **Proven alternative to conventional activated sludge (CAS) system**
  - **Advantages include:**
    - **Removes the need for secondary clarification (no bulking problem)**
    - **Can be operated and maintained at higher biomass concentrations**
  - **Disadvantages include:**
    - **High capital costs**
    - **High energy usage**
    - **High maintenance requirements**
- **Dynamic filter (e.g., nonwoven fabric (>50 µm)**
  - **May address the problems of MBRs, but other disadvantages include:**
    - **Difficulty in controlling dynamic layer**
    - **Low solids removal efficiency**

Uses

- **Biological Nutrient Removal (BNR)**
  - **When nutrient control is required, BNR is an inexpensive method that can be used in existing WWTPs with minor modifications**
  - **Additional advantages to BNR include:**
    - **Decreased aeration requirements**
    - **Decreased biomass production**
    - **Decreased biomass (sludge) bulking**
  - **MBRs not typically used for BNR**
    - **BNR requires minimizing oxygen concentration while MBRs require strong airflow for scouring the membrane surface**
    - **Examples of researchers achieving BNR in MBRs**
      - **Modified DEPHONEX system (Patel *et al*., 2005)**
      - **Single zone baffled MBR (Kimura *et al*., 2007)**
    - **Disadvantages are energy use and capital cost**

Other Uses

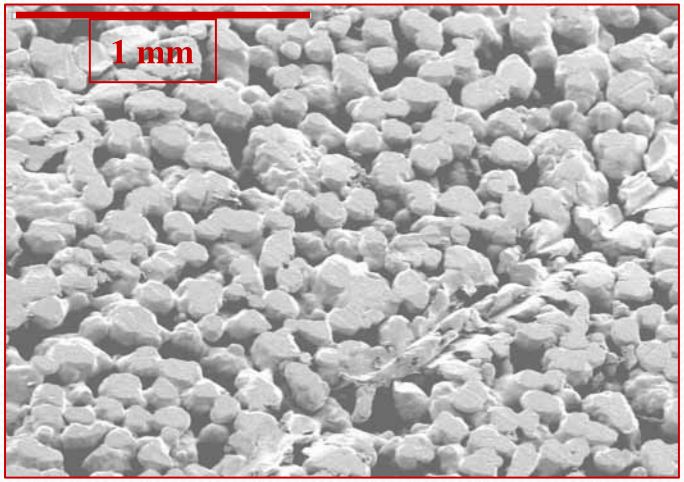
- **Removal/Control of Chemicals of Concern (COCs) from wastewater**
  - **Include endocrine disrupting compounds (EDCs), pesticides, and pharmaceutical and personal care products (PPCPs)**
    - **Adverse impacts on human health and ecosystems**
    - **Widely distributed in wastewater**
    - **Some reports on removal mechanisms by field surveys and batch experiments (e.g., Marfil *et al*., 2010)**
      - **But effects of anoxic condition and solids retention time (SRT) on COCs removal under long-term operation are uncertain**
- **Conventionally operated wastewater treatment plants do not provide an effective barrier against the release of these COCs to receiving waters**

Biomass Concentrator Reactor (BCR)

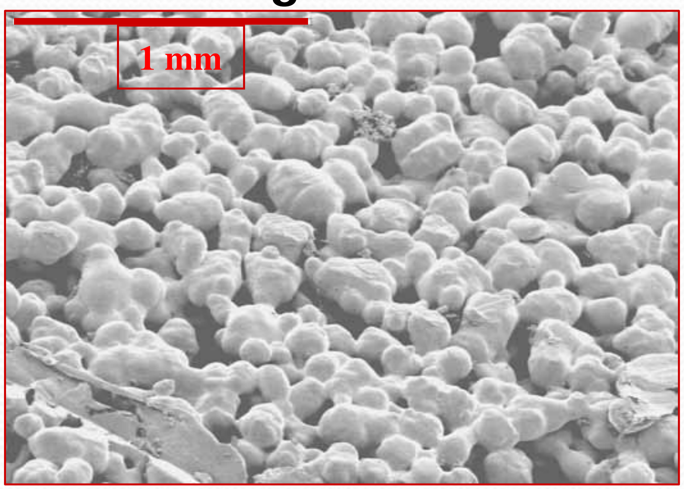
- **Biomass Concentrator Reactor (BCR)**
  - **Co-developed and patented by EPA-NRMRL and the University of Cincinnati**
  - **Constructed of packed polyethylene beads with an effective pore size range of 18~28 µm**
  - **Low pressure (gravity flow) operation, < 2.5 cm hydraulic head**
  - **Innovative wastewater treatment technology with excellent efficiency, low energy consumption, ease of operation**
- **Developed for treating groundwater contaminated with MTBE and hydrocarbons**
  - **MTBE biodegradation exceeded 99.9%**
  - **Applicability of BCR to municipal wastewater treatment has not been demonstrated**

SEM Close-Up of BCR Membrane

Smooth Side



Rough Side



Membrane: Polyethylene
Pore Size: 18 - 28 µm
Thickness: 2 to 4 mm

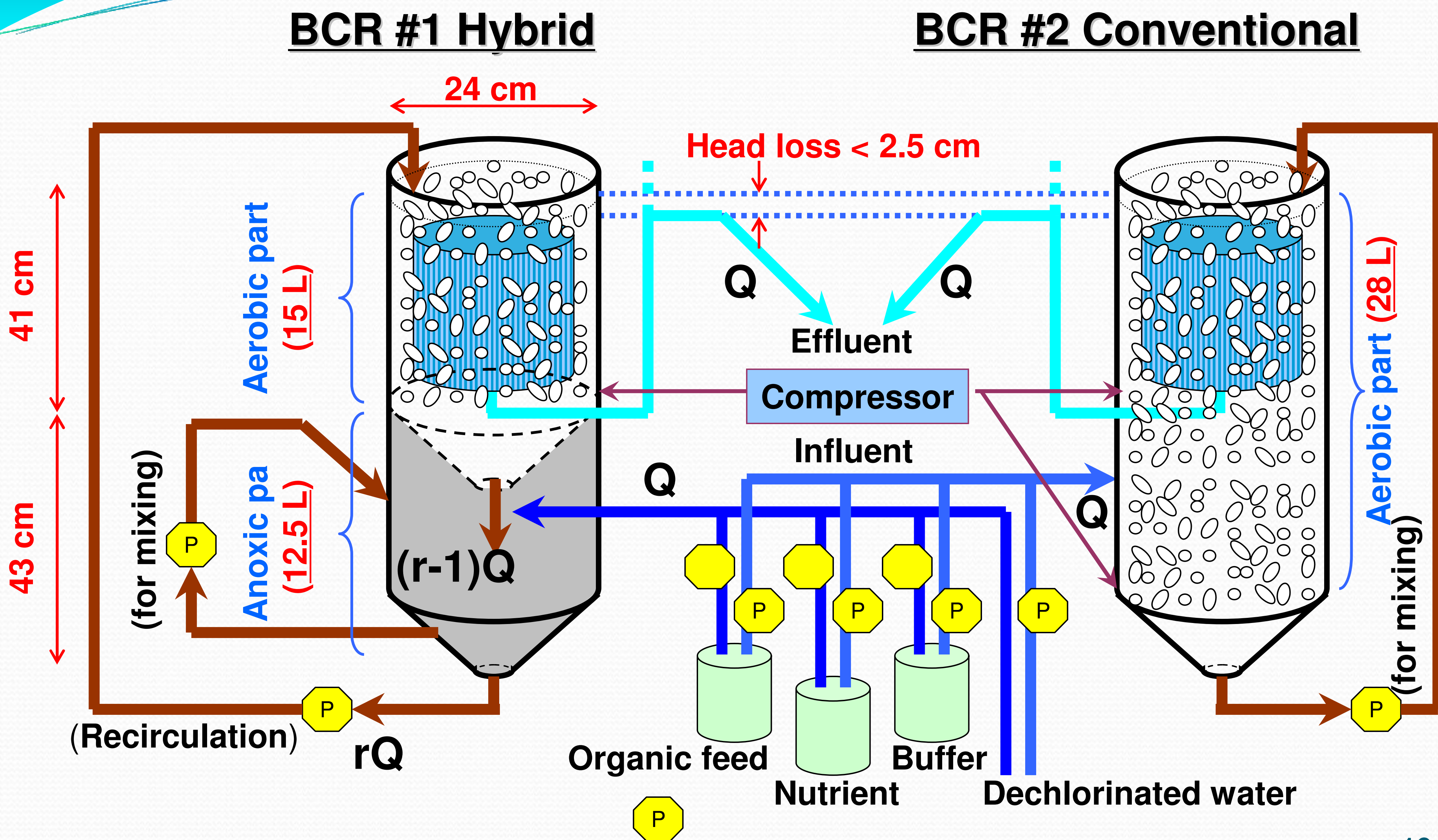
Objectives

- To develop and test a modified BCR for BNR and compare results to other MBR systems
- To evaluate removal of specific COCs under different operational conditions
  - Different aerobic/anoxic conditions
  - Varying solids retention time (SRT)
    - Longer SRTs may select species able to degrade COCs that would not normally develop under conventional SRTs

Materials and Methods

- **Two laboratory-scale reactors continuously operated using synthetic wastewater**
  - **BCR #1: Hybrid condition (aerobic and anoxic compartments for BNR)**
  - **BCR #2: Conventional condition (aerobic only)**
- **Operation**
  - **Biomass collected from a local municipal wastewater treatment plant**
  - **Daily wasting of biomass at a fixed mixed liquor volume to maintain constant SRT**
  - **Dissolved Oxygen (DO) control for aerobic conditions (> 6 mg/L) and anoxic conditions (< 0.1 mg/L)**
  - **Temperature maintained at 20 ± 3 ℃**
  - **Daily cleaning of reactor walls by mixed liquor flushing at high flow**
  - **Membrane chemically cleaned when head loss > 2.5 cm (1x/6 months)**

Materials and Methods (cont'd)



Photos of the Two Reactors

Materials and Methods (cont'd)

Table 1. Summary of operating conditions for BCR #1				
Condition	Time, d	HRT, h	SRT, d	Recycle Ratio
Initial Start Up	0-85	9	6	2-3
Run #1	86-177	9	6	3
Run #2	178-310	9	15	3

Synthetic Wastewater Composition

- COD ~ 200 mg/L
- NH_4-N ~ 30 mg/L
- TKN ~ 35 mg/L
- NO_2-N and NO_3-N = 0 mg/L
- COCs = 10 µg each

Component	Final Concentration, mg/L
Substrates and macronutrients	
Casein	47.0
Tryptone	47.0
Starch	84.4
Sodium acetate	31.9
Glycerol	12.0
Caproic acid	11.6
Ammonium sulfate	116.0
Magnesium sulfate	69.6
Calcium chloride	22.5
Potassium phosphate	27.6
Micronutrients	
Cupric sulfate	0.09
Sodium molybdate	0.15
Manganese sulfate	0.13
Zinc chloride	0.23
Iron chloride	0.42
Cobalt chloride	0.42
Buffer	
Sodium carbonate	248.6

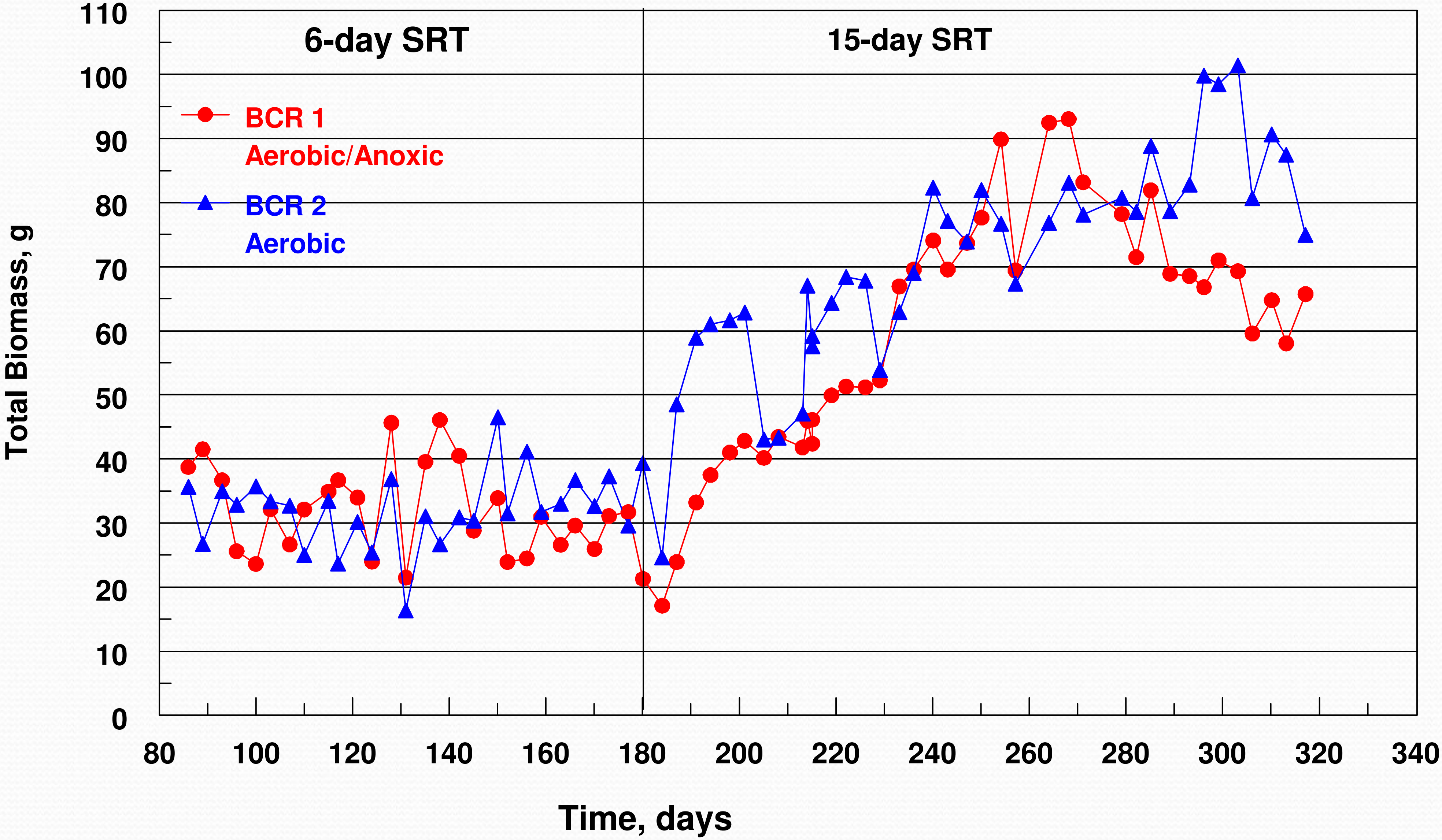
COCs Used

- 10 trace COCs (each 10 µg/L) in influent
  - Caffeine (CAF)
  - Atrazine (ATR)
  - Carbamazapine (CMP)
  - Testosterone (TES)
  - Progesterone (PRO)
  - Ethinylestradiol (EE2)
  - Triclosan (TCS)
  - Nonylphenol (NP)
  - NP-ethoxlyate (NPE)
  - NP-diethoxylate (NPDE)

Control of Conditions

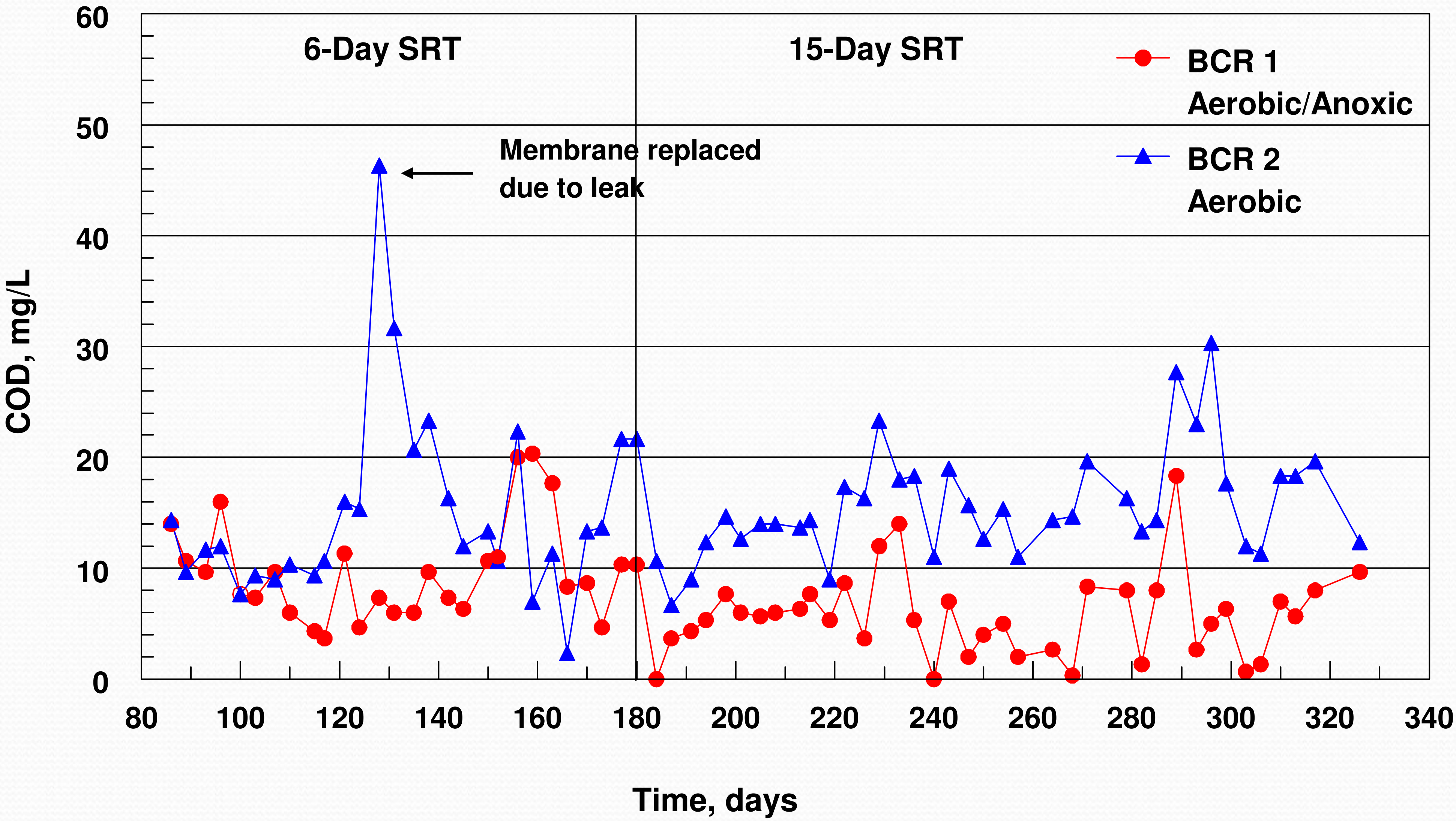
Measurement	Frequency	Method	Instrument
Flow Rates	Daily	Daily record keeping of reservoir levels and total effluent flow rate including tap water	Measuring cylinder and timer
Temperature	Daily	Thermometer	Mercury thermometer
pH	Daily	pH meter	Oakton WD-35801-00 pH Electrode
TSS/VSS	Twice Weekly	Standard method 2540D/2540E	Ohaus AP250D Scale
COD	Twice Weekly	HACH Spectrophotometer Method #8000	HACH DR/2000 Spectrophotometer
Ammonia	Twice Weekly	Ammonia meter	Orion 9512HPBNWP Ammonia Electrode
Nitrate, Nitrite	Twice Weekly	Ion Chromatagraphic Method	Dionex LC20 Ion Exchange Chromatagraph
TKN	Twice Weekly	HACH Spectrophotometer Method #8075	HACH Digesdahl Digestion Apparatus 23130-20 & HACH DR/2000 Spectrophotometer
COCs	Once Weekly, 4 times for each Run	LC/MS/MS	Agilent 1200 Series rapid resolution LC system coupled to an Agilent 6410 Triple Quad MS/MS equipped with an orthogonal ESI interface

Results: Total Biomass in Reactors

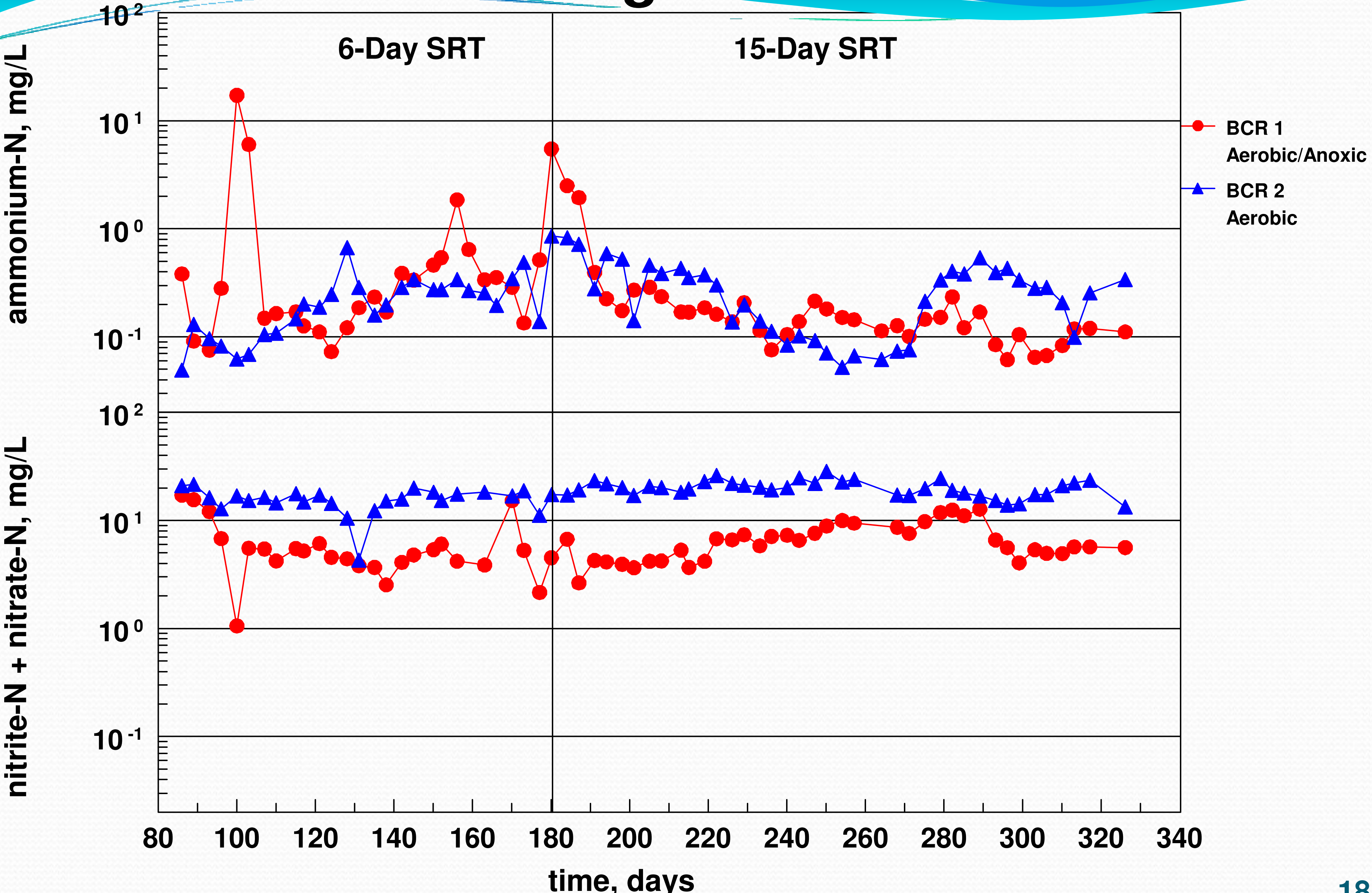


Results: COD in Effluent

- Avg. influent COD = 212 mg/L



Results: nitrogen in effluent



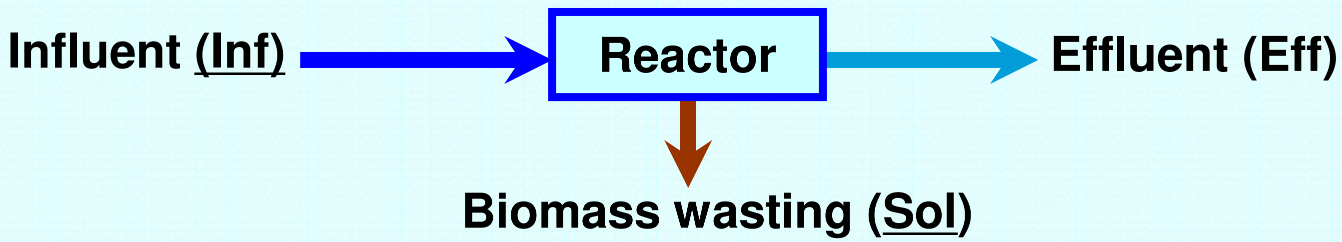
Summary of COD and Total N Treatment Performance

Reactor	HRT, h	SRT, d	COD removal, %	TN removal, %
BCR 1 (hybrid)	9	6	95	79
	9	15	97	75
BCR 2 (aerobic)	9	6	93	53
	9	15	93	43
Patel *et al*. (2005) [conventional MBR]	12	20	99	77
Kimura *et al*. (2008) [conventional MBR]	4.7	29	85	77

Treatment performance of the developed BCR was as good as conventional MBR with significantly less energy requirement

Results – COCs

- **Effects of the anoxic condition and SRT on COC removal were significant**



Removal % = [(Inf) − (Eff) − (Sol)] / (Inf)*100

Units = ug/d

BCR 1 (hybrid)

COC	Influent, µg/d	6 d SRT Operation, µg/d			15 d SRT Operation, µg/d		
		Effluent	Solids	% Removed	Effluent	Solids	% Removed
CAF	713	27.9	0.6	96.0	4.3	0.2	99.4
ATR	713	367	0.8	48.4	279	0.2	60.9
CMP	713	420	0.3	41.0	336	0.6	52.7
TES	713	1.7	0.1	99.7	1.4	0.1	99.8
PRO	713	2.0	0.2	99.7	1.8	0.1	99.7
EE2	713	199	3.0	71.6	91.3	0.6	87.1
TCS	713	8.1	4.6	98.2	3.8	0.9	99.3
NP	713	7.5	1.6	98.7	6.1	0.5	99.1
NPE	713	8.2	2.2	98.5	7.2	0.7	98.9
NPDE	713	5 3	1 3	99 1	3 8	0 4	99 4

BCR 2 (conventional)

COC	Influent, µg/d	6 d SRT Operation, µg/d			15 d SRT Operation, µg/d		
		Effluent	Solids	% Removed	Effluent	Solids	% Removed
CAF	713	71.8	1.0	89.8	47.0	0.3	93.4
ATR	713	290	0.6	59.2	261	0.5	63.3
CMP	713	334	0.3	53.1	336	0.6	52.8
TES	713	1.8	0.1	99.7	2.0	0.2	99.7
PRO	713	2.0	0.1	99.7	1.8	0.2	99.7
EE2	713	39.3	0.7	94.4	28.8	0.3	95.9
TCS	713	8.7	3.1	98.4	9.0	1.5	98.5
NP	713	6.0	1.3	99.0	4.4	0.6	99.3
NPE	713	6.8	0.8	98.9	4.8	1.8	99.1
NPDE	713	5 2	0 9	99 2	2 8	0 6	99 5

Conclusions

- Both BCRs resulted in good biomass separation, producing effluent substantially free of suspended solids
- Conventional BCR effected excellent COD and NH_3 oxidation
  - Hybrid BCR also produced excellent NO_2 and NO_3 reduction (BNR by denitrification)
- Both BCRs produced > 90% removal (mostly > 95%) of 8 of the 10 COCs and > 50% removal of the remaining 2 COCs (atrazine and carbamazapine)
  - Increased SRT in the hybrid BCR resulted in even higher COC removal
- In regard to ethinylestradiol (EE2), we have some evidence to suggest that it polymerizes during aerobic operation, so some of the “removal” shown may have been due to a non-biological mechanism
- Treatment performance of the BCR is as good as MBR, with less energy and capital requirements

Recommendation

- Since even higher SRTs are possible in the BCR, we propose the hybrid design for treatment of municipal wastewater to levels that allow water reuse
  - Further improvements would result in wastewater treatment for producing safe drinking water sustainably

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