Research findings with anaerobic fluidized bed membrane bioreactor (AFMBR) systems

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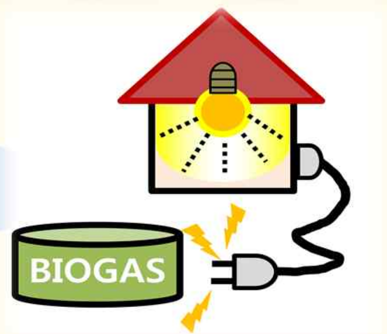
Wastewater is Resources

Water

N & P

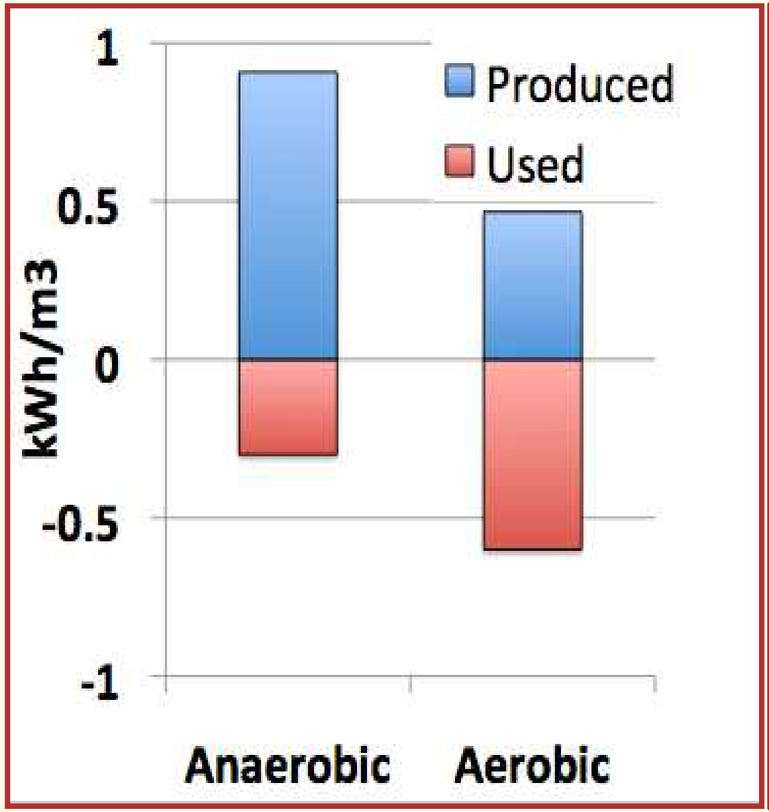
Wastewater

Energy

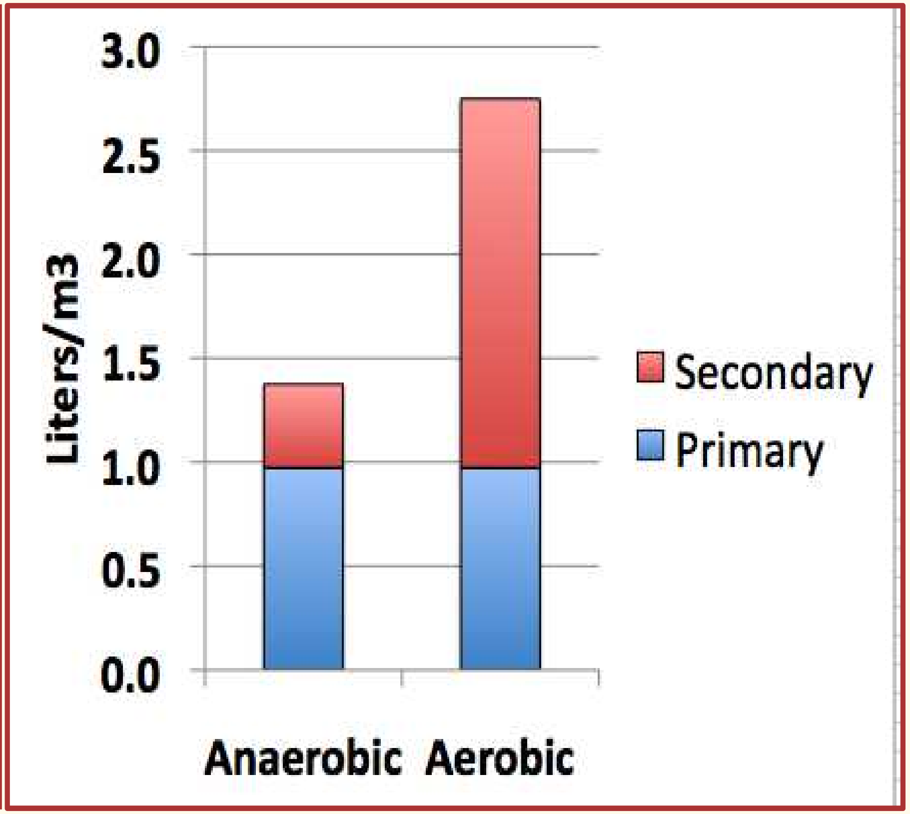


Why Anaerobic?

- Energy



- Sludge



Wastewater: BOD = 200 mg/L, VSS = 192 mg/L

Why Membrane Bioreactor?

Full-Scale System Comparisons (Brazil)

		BOD (Avg)		
System	No.	Inf mg/L	Eff mg/L	Rem (%)
Activated Sludge	**13**	**315**	**35**	**85**
USAB	**10**	**371**	**98**	**72**
USAB + post treatment	**8**	**362**	**42**	**88**

Oliveira and Sperling, *Water Research*, **42**, 1182 (2008)

Why Membrane Bioreactor?

- Membrane prevents
  - loss of active methanogens
  - escape of VSS so that they can be degraded
    - limitation with slow hydrolysis can be overcome
- Membrane improves
  - effluent quality by filtration

- Potential problem: fouling control
  - energy demand for gas sparging in AnMBR
    - 0.6 ~ 1.6 kWh/m^3
  - chemical cleaning

Why Fluidized Bed Reactor?

Performances of the AFBR at similar OLRs

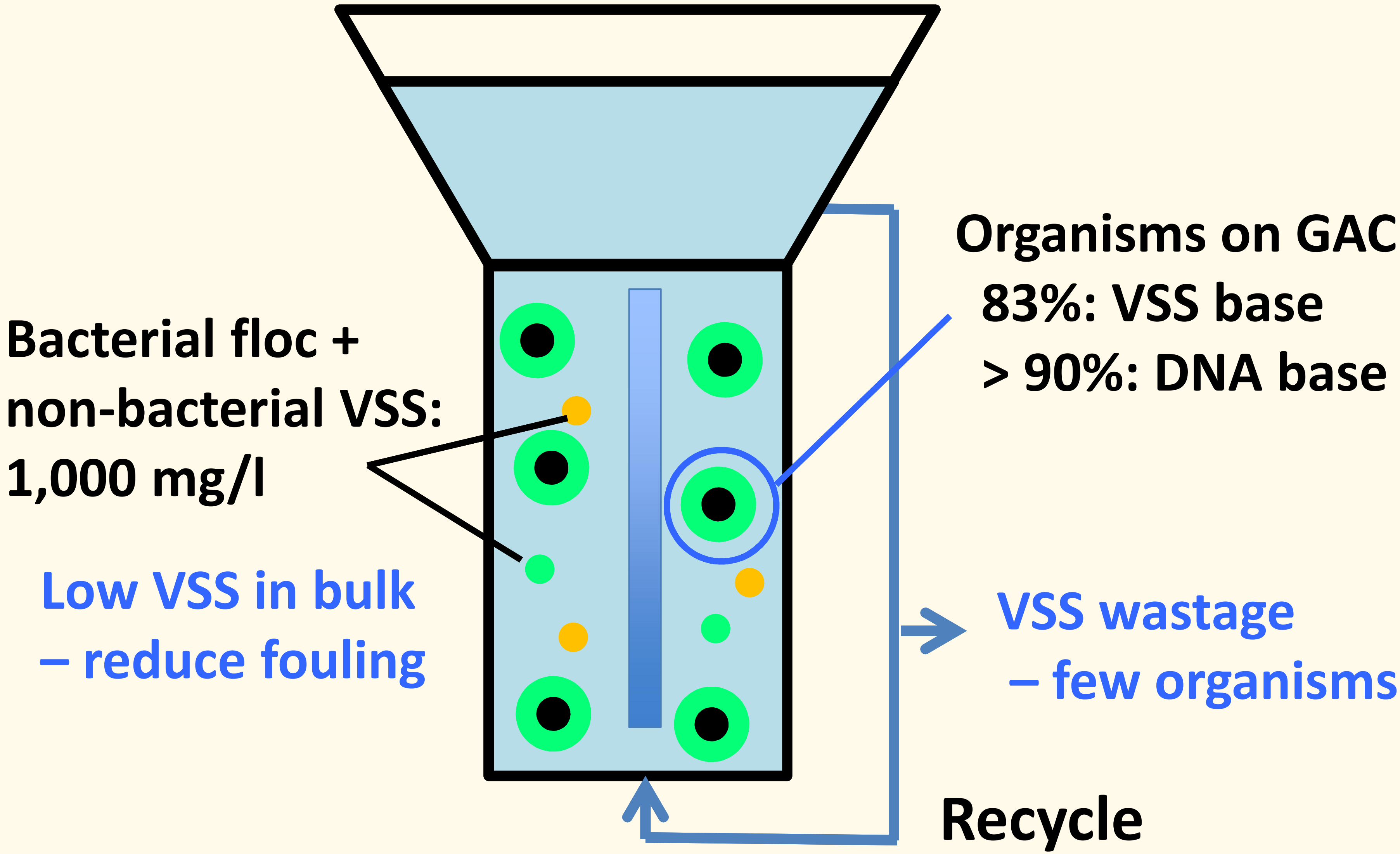
Mode (operating days)	I (90)	II (20)	III (20)
OLR (kg COD/m^3-d)	4.2	4.4	4.3
HRT (h)	11.50	2.87	0.72
Inf. COD (mg /L)	2,010	523	130
COD removal (%)	97%	93%	89%
acetate(mg/L)	< 0.4	< 0.4	< 0.4
propionate (mg /L)	< 0.3	< 0.3	< 0.3

Why Fluidized Bed Reactor?

- FBR has several advantages
  - high mass transfer of substrate to the biofilm
  - no problems of channeling and clogging
  - maintenance of high biomass at short HRT
  - small footprint requirement
- Fluidized particles can be used
  - a low-energy membrane fouling control method
  - GAC adsorption further reduces fouling

Fouling Control with GAC Fluidization

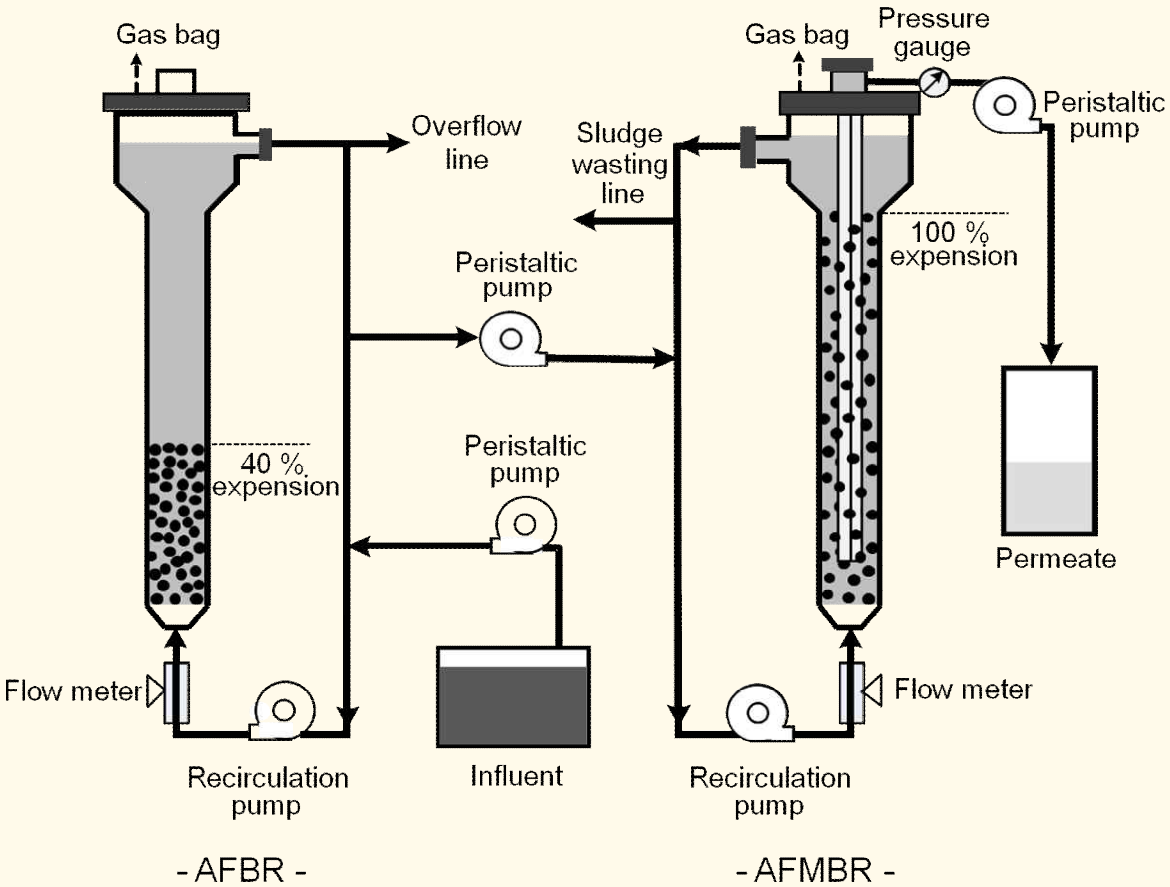
Additional Benefits of GAC



AFMBR Characteristics

- Anaerobic methanogenic system
  - produces net positive energy and less biosolids
  - has a small footprint
- Membrane bioreactor with GAC
  - separates organism SRT from bulk VSS SRT
  - achieves high organic removal at short HRT
  - provides operational stability with sorption
  - removes hazardous chemicals

Staged Anaerobic Fluidized MBR (SAF-MBR)



Shin et al., Bioresour. Technology, 159:95(2014)

10 m³/day Pilot SAF-MBR at Bucheon

Pilot SAF-MBR Membrane Module

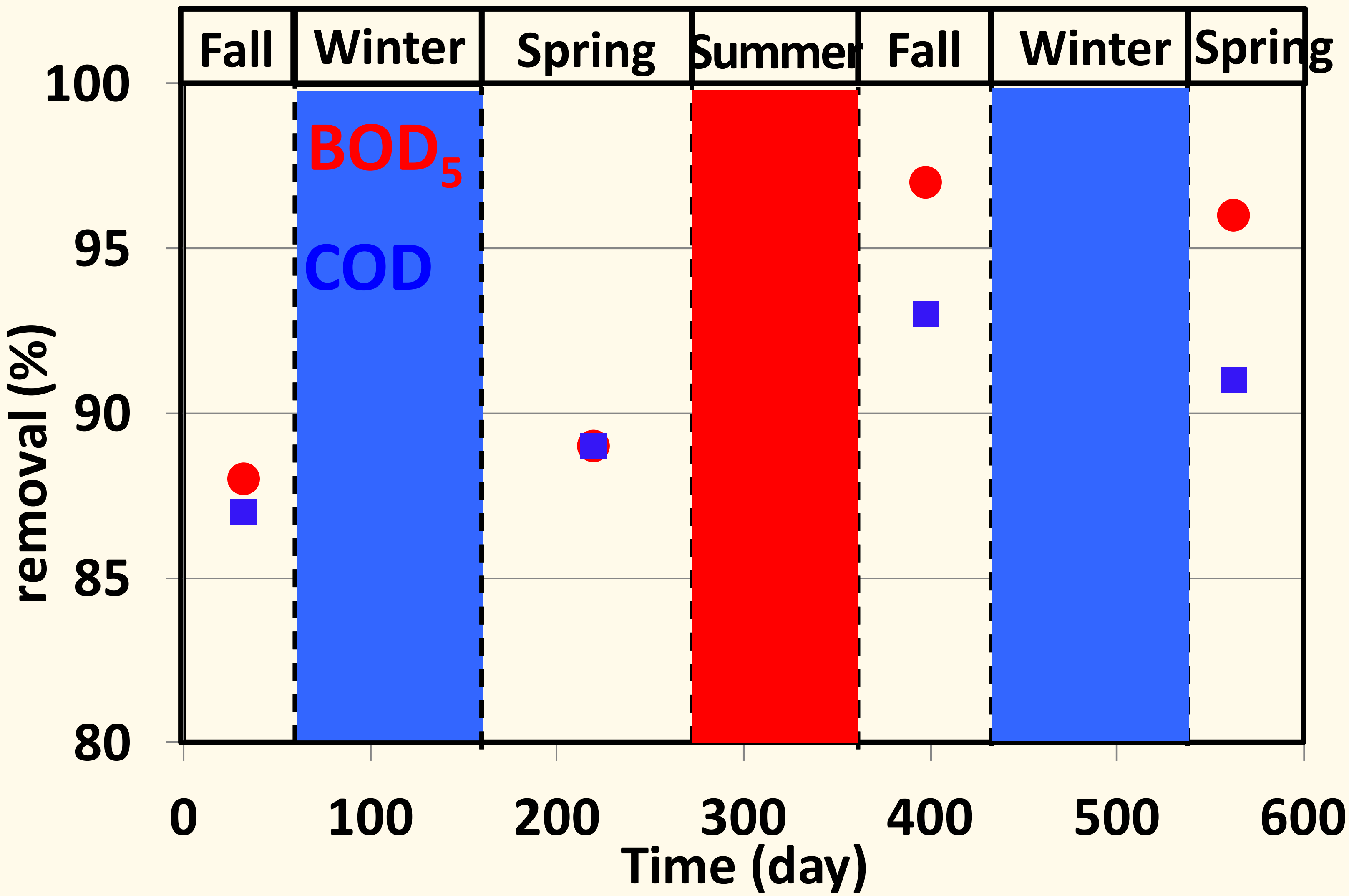
- PVDF Hollow fiber membranes
  - Pore size: 0.03 μm
  - Total surface area: 39.5 m^2

membrane density is 25% of that of commercial module

Pilot SAF-MBR Operation

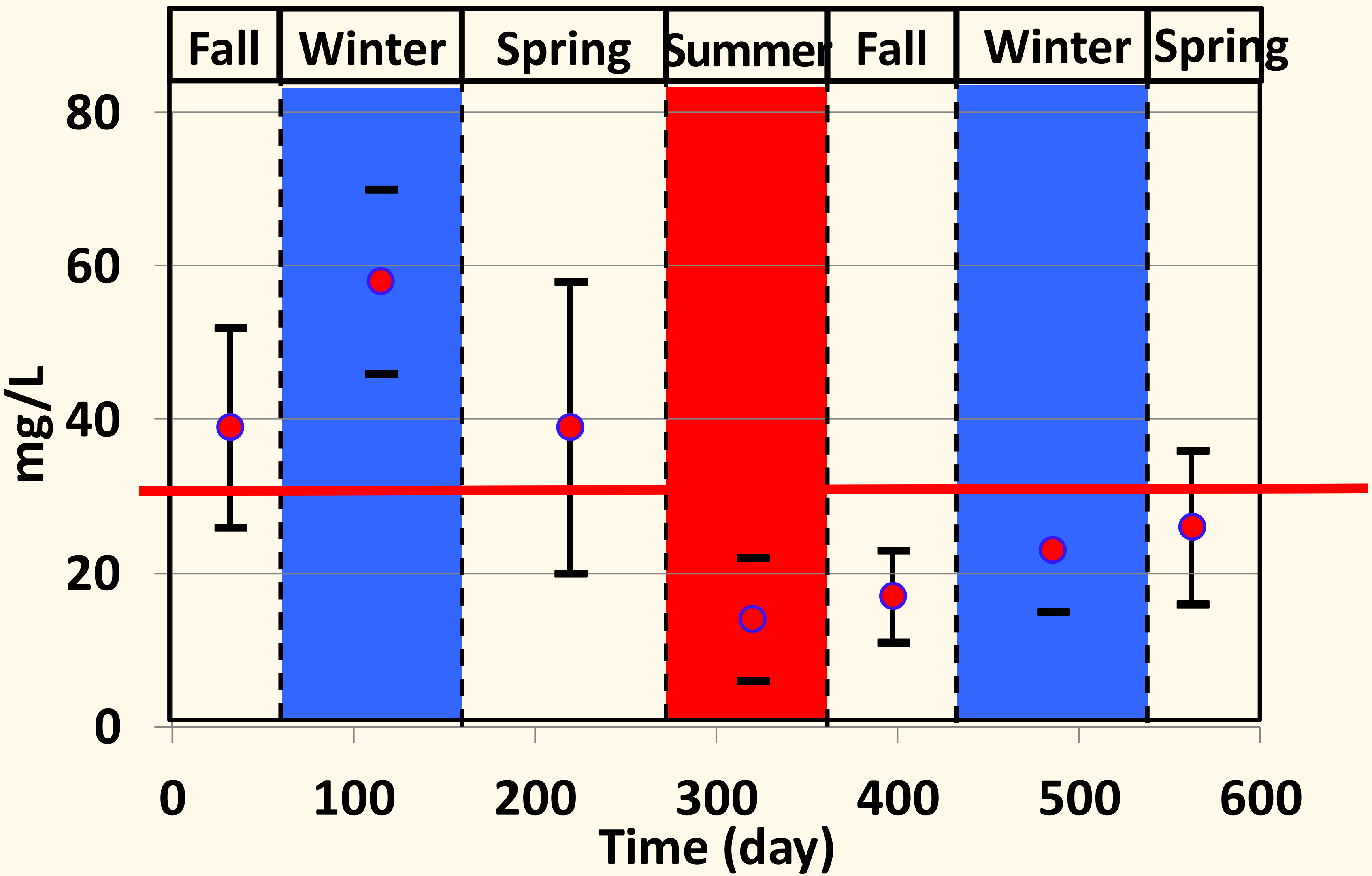
- **Feed characteristics (primary clarifier effluent)**
  - COD 300 ± 60 mg/L
  - BOD_5 160 ± 45 mg/L
- **HRT**
  - AFBR 2 h
  - AFMBR 2.6 ~ 4.8 h (net flux: 4.1 ~ 7.5 $L/m^2/h$)
  - Total 4.6 ~ 6.8 h
- **Temperature**
  - Spring & Fall: 15 ~ 25 ^oC
  - Summer: 25 ~ 30 ^oC
  - Winter: 8 ~ 15 ^oC

COD & BOD_5 Removals



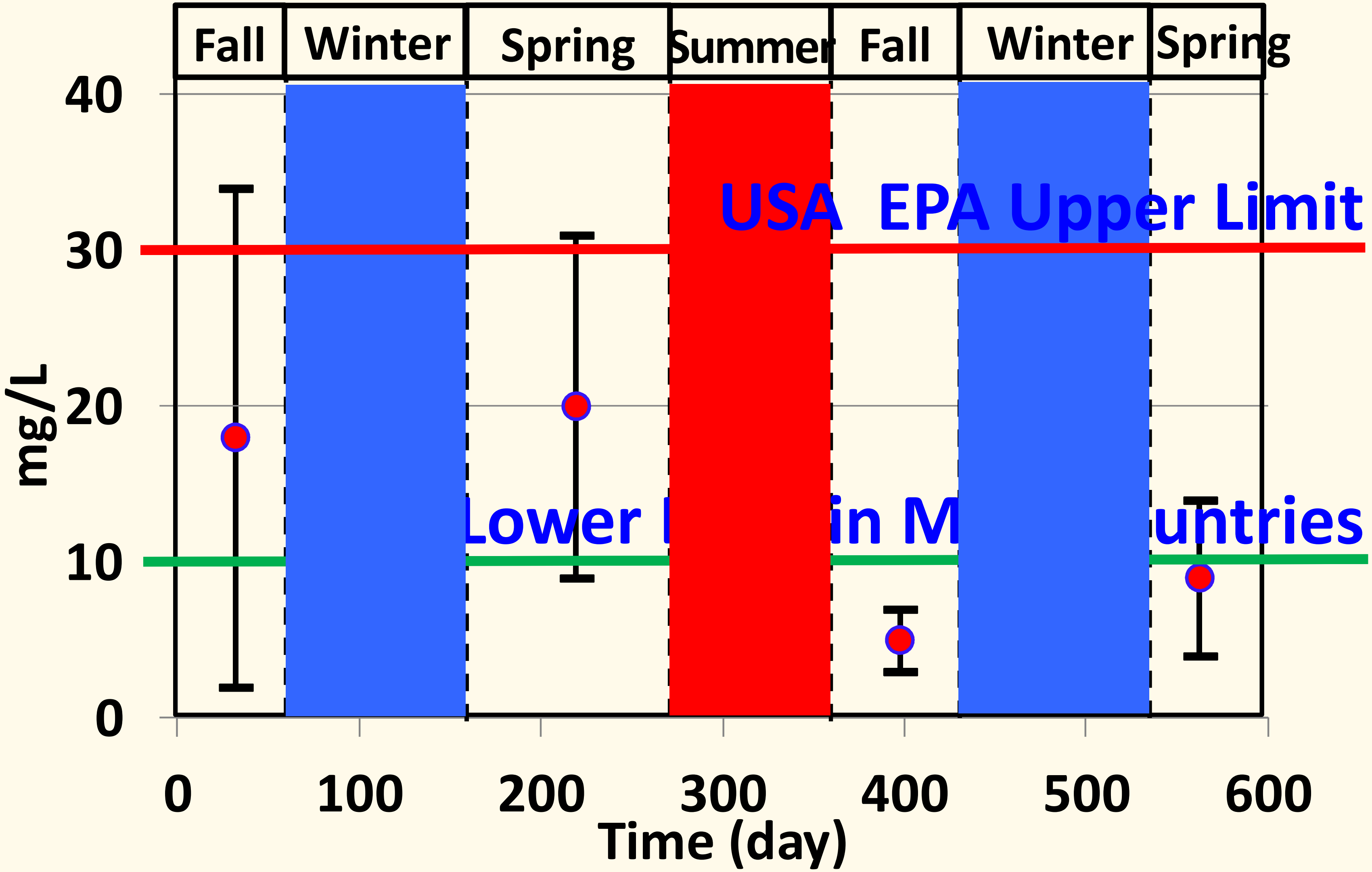
Shin et al., Bioresour. Technology, 159:95(2014)

Effluent COD



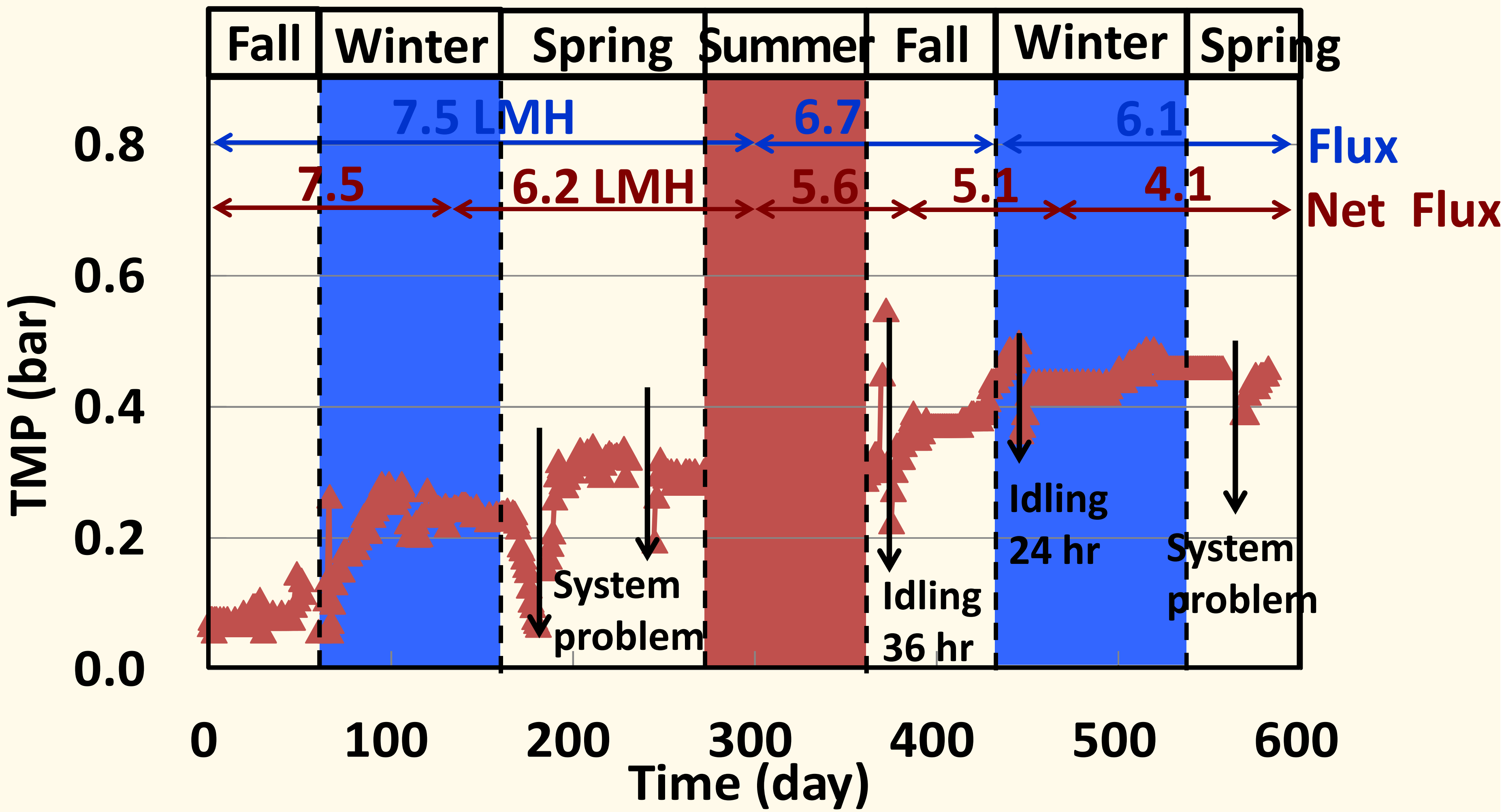
Shin et al., Bioresour. Technology, 159:95(2014)

Effluent BOD_5



Shin et al., Bioresour. Technology, 159:95(2014)

TMP and Flux Variation



Shin et al., Bioresour. Technology, 159:95(2014)

Biosoids Production

0.05 kg VSS/kg COD removed

and

Already digested

and

Less than one-quarter of that
from aerobic treatment

Shin et al., Bioresour. Technology, 159:95(2014)

Electrical Energy Balance – kWh/m³

	Energy consumption[1)]			CH_4 Energy Potential
	Main reactor	Recycle line	Total	
AFBR	0.016		0.016	
AFMBR	0.103	0.108	0.211	
Total	0.119	0.108	**0.227**	**0.139**
Changes in new AFMBR diameter of the recycle line (10 -> 20 mm) membrane surface area from 40 to 67 m² influent from clarifier effluent to clarifier influent; COD increase by 35%				
AFMBR	**0.086**	**0.021**	0.107	
Total	**0.102**	**0.021**	**0.123**	**0.188**

[1)] assuming 65% of pump efficiency 33% of conversion efficiency of methane to electricity and net flux of 6.2 LMH

Degree of Negative Effect of GAC on Membrane Integrity

- Fine AC particles
  - cause fouling by blocking the pores
  - production potential needs to be addressed

- GAC induced membrane integrity loss
  - additional cost for membrane replacement
  - extent of integrity loss needs to be evaluated

No Changes in GAC Mass Fraction after 2 years of Operation

- Size range of GAC used

Size (mm)	Distribution (mass %)
0.80 ~ 1.00	8
1.00~ 1.40	34
1.40 ~ 2.00	20
2.00 ~ 4.00	38

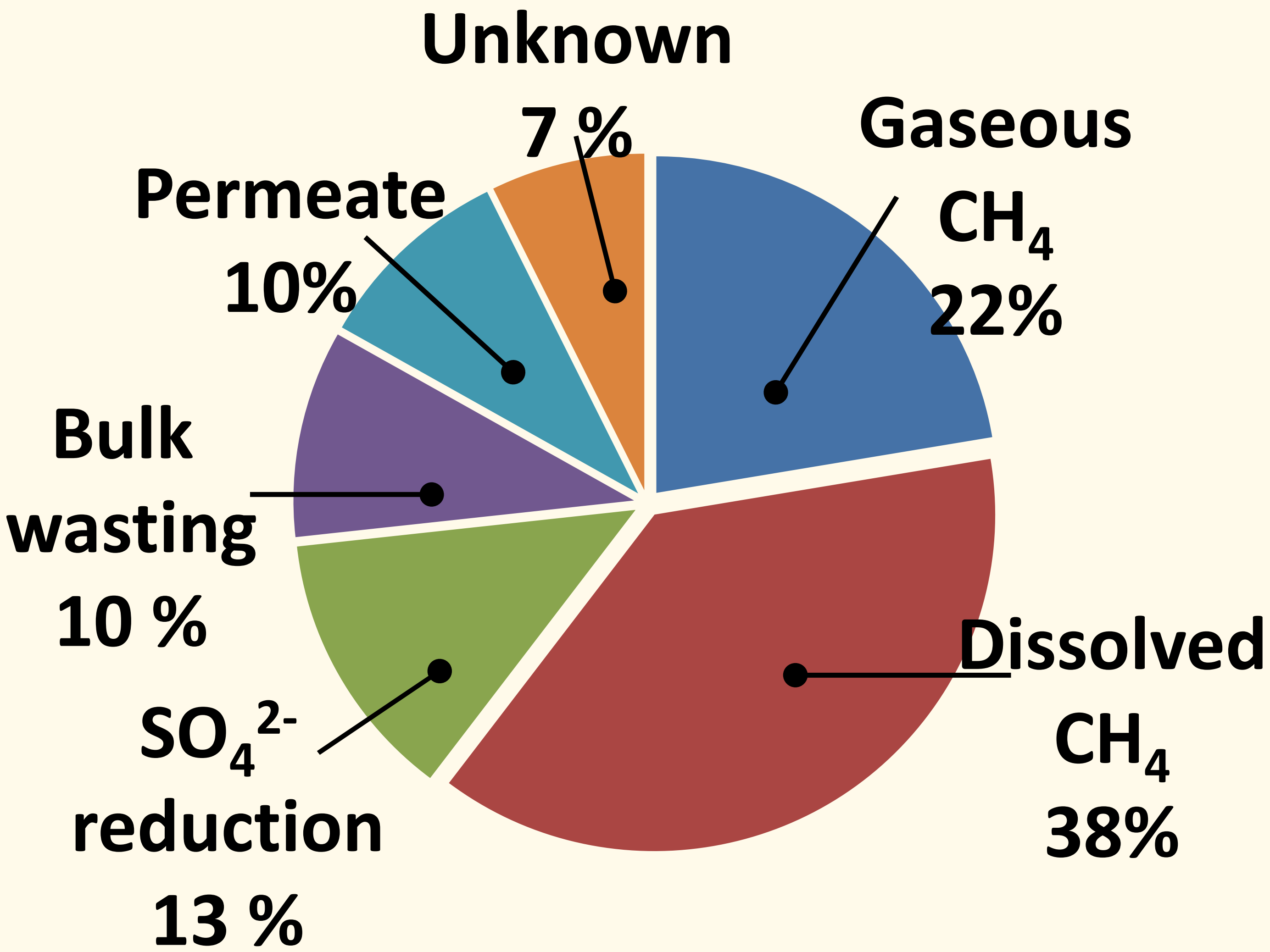
- GAC mass fraction in the above size range

	mass (%)
before experiment	99.3
GAC from the AFBR	99.5
GAC from the AFMBR	99.4

Research Needs

- How best to recover dissolved methane?
- How best to optimize AFMBR?
  - What are the best membranes to use?
  - How and when to chemically clean membranes?
  - What is best media to use for fluidization?
- How best to remove and/or recover nutrients?
  - Phosphorus – $FeCl_3$ precipitation
  - Ammonia-nitrogen
    - Autotrophic denitrification (anammox)
    - Ion exchange and capture with ammonium selective resin
    - CANDO

Importance of Dissolved Methane



COD Mass Balance of the SAF-MBR (Winter)

Low-Energy Low-Cost Dissolved Methane Removal Technologies

- Stripping tower
- Venturi
- Gas permeable membranes
- Vacuum degasification

Commercial Methane Removal Systems

Organics Stripping tower

Energy < 0.05 kWh/m^3

Removal > 99%

Groundwater and WW

Scomi Oiltools vacuum degasser

Energy < 0.02 kWh/m^3

Removal > 99.9%

Drilling fluid

Conclusions

- Efficient AFMBR treatment of domestic WW in temperate climates is possible.

  - BOD_5 removal of > 95% at 6 h HRT and 8^{o}C

  - significant reduction in biosolids production

- AFMBR, in which membrane fouling is uniquely controlled by the fluidized GAC, could become energy self-sufficient process.
- The AFMBR system needs to be evaluated in a LCSA, to ensue better quality and transparency for decision makers and process designers.

Energy-Producing

SAF-MBR

Will Come Soon!