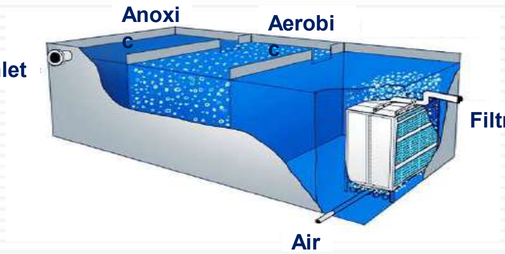
Membrane Aerated Biofilm Reactors: Advantages over Conventional Systems and Possible Modifications

IESL Young Engineers Day, 20th February 2020



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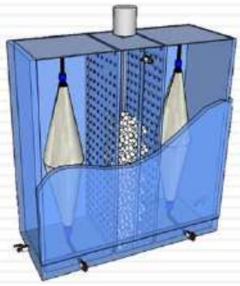

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Contaminants in Domestic Wastewater

Contaminant	Concentration			
	Unit	Low strength	Medium strength	High strength
Total dissolved solids (TDS)	mg/L	270	500	860
Total suspended solids (TSS)	mg/L	120	210	400
Biochemical oxygen demand (BOD)	mg/L	110	190	350
Chemical oxygen demand (COD)	mg/L	250	430	800
Total nitrogen (TN)	mg/L	20	40	70
Total phosphorus (TP)	mg/L	4	7	12
Volatile organic compounds (VOCs)	µg/L	<100	100-400	>400

(Metcalf and Eddy, 2003)

- Wastewater produced in many cities is characterized with low COD/N ratio (≤ 5) (Sun et al., 2010)

Impacts due to Contaminants

Impacts

N
- High algae
- Low DO
- Toxicity
- Death of aquatic life
- Blue baby syndrome
- Growth of cyanobacteria
- Poor larval growth and reduced body size of fish
- Odour
- Decolouration of water

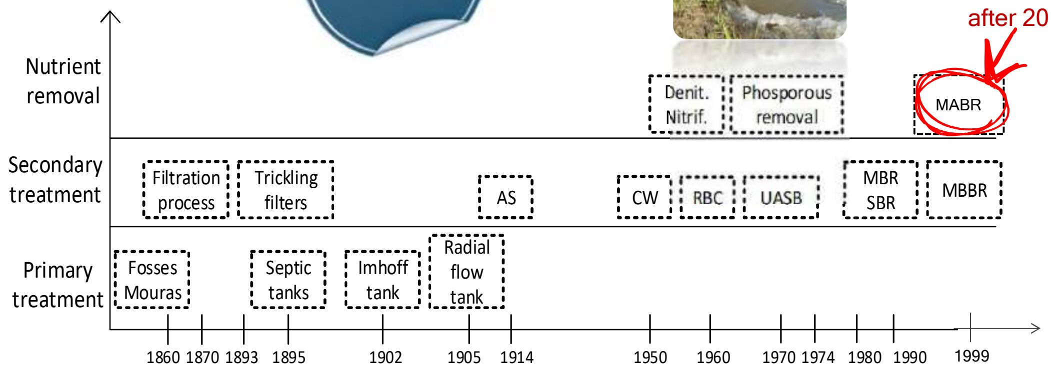
P
- Odours
- Decolouration of water
- DO depletion
- Algal blooms
- Dead macrophytes and phytoplankton settle to the bottom of a water body

SS
- Reduced photosynthesis
- Physical harm to fish
- Toxic effects from contaminants attachment

COD
- Low DO
- Increasing fish susceptibility to diseases
- Changes in species composition

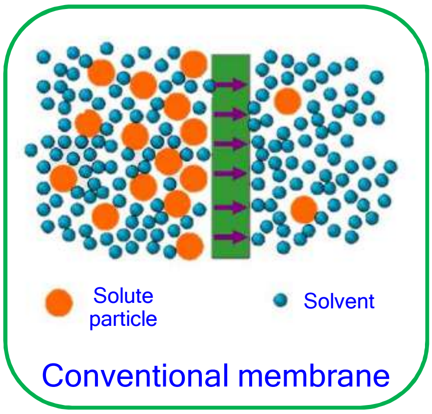
Evolution of Wastewater Treatment

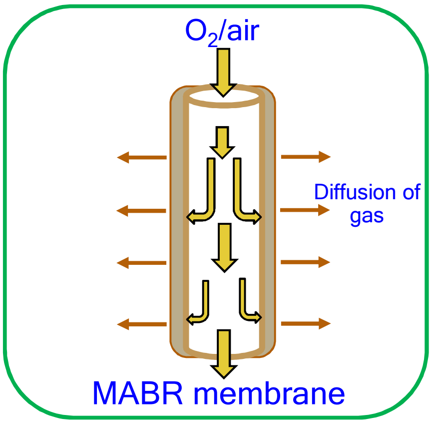
Commercialized only after 2013



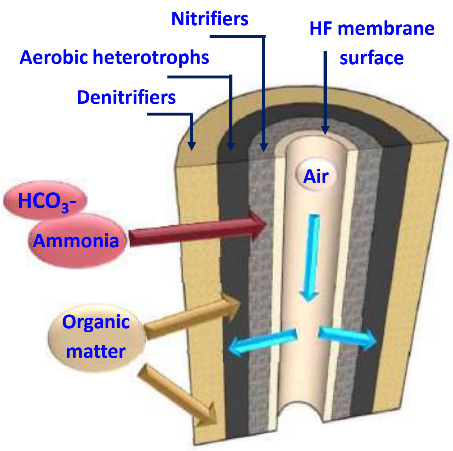
Membrane used in MABR

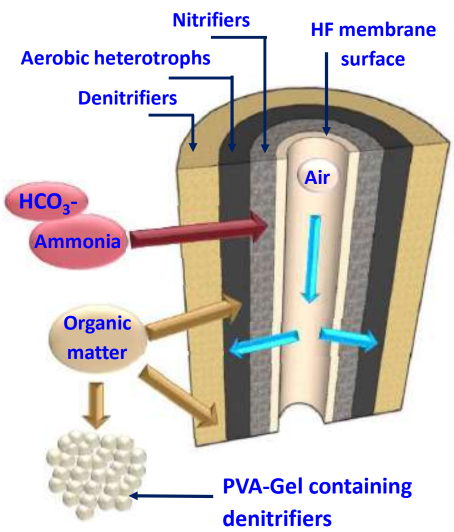
- Membrane aerated biofilm reactor (MABR) is an emerging technology using gas supplying membranes



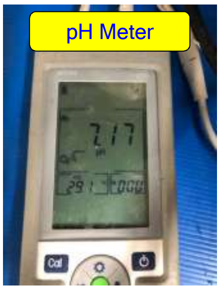


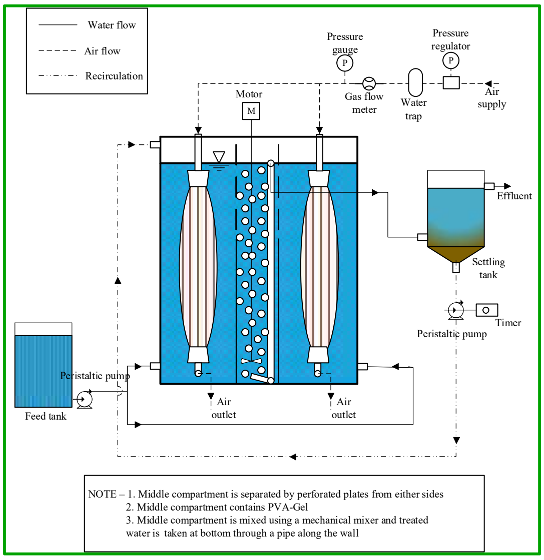
MABR Operation





Equipment and Setup





TN and COD Removal Comparison with Previous Studies

No.	Feed water	Membrane type	COD/N ratio	Influent TN con. (mg/L)	Reactor volume (L)	HRT (h)	COD removal (%)	TN removal (%)	Reference
1	Synthetic surface water	PVDF HF membrane	8	25	470	36	80	60.3	Li and Zhang, 2017
2	Typical municipal RO concentrate	HF membrane	5.8	75	6	24	>85	79.2	Quan et al., 2018
3	Synthetic WW	Dense non-porous HF	4.4	27.2	0.8	6	91.6	46.3	Duvall, 2017
4	Synthetic WW	PDMS HF membrane	4	40	3	12	95.1	50.23	Akkakarn, 2018
5	Synthetic WW	MHF 200 TL HF membrane	4	40	3	12	91.1	47.64	Akkakarn, 2018
6	Synthetic WW	PDMS HF membrane	4	40	3	8	90	30.66	Akkakarn, 2018
7	Synthetic WW	MHF 200 TL HF membrane	4	40	3	8	86	31.59	Akkakarn, 2018
8	**Synthetic WW**	**PDMS HF membrane**	**6**	**40**	**6**	**12**	**>92.2**	**68.63**	**This study**

Conclusions

- COD removal performance was always above 90% and had slight variations throughout the whole experimental duration. COD removal was not affected by the addition of PVA-Gel bio-carriers, by changing the COD/N ratio or by changing the HRT.
- The MABR performance increased due to the addition of PVA-Gel containing denitrifiers.
- Maximum TN removal was 68.63% at 12h HRT and COD/N ratio of 6. This result is better than the results of previous studies. Because, the HRT of 12h in this study is low compared to previous studies.

Recommendations for Future Studies

1. Conduct further experiments by changing the PVA-Gel volume
2. Quantify the sludge reduction due to the use of PVA-Gel
3. Conduct further experiments to standardize a process for biofilm thickness control by PVA-Gel
4. Use qPCR technique to get an insight on microbiology in the biofilm

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Enhancement of organic matter and total nitrogen removal in a membrane aerated biofilm reactor using PVA-Gel bio-carriers

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ABSTRACT

The Membrane Aerated Biofilm Reactor (MABR) is an attractive alternative for the removal of nitrogen from wastewater because of its ability to overcome the inherent limitations of conventional systems. But in MABR, the denitrification performance is low at low Hydraulic Retention Times (HRT). Therefore, a modified MABR which uses Polyvinyl Alcohol (PVA) gel beads as bio-carriers was used in this study to enhance the Total Nitrogen (TN) removal efficiency when treating domestic wastewater.

By adding PVA-Gel in the MABR, the nitrification and TN removal performances increased by 14% and 13.4% respectively. At 12 h HRT and COD/N = 6, it had a maximum TN removal efficiency of 68.63%. The COD removal performance was always above 90.2%. Moreover, in contrast to a conventional MABR, the nitrification rate had an upward trend when the COD/N ratio was increased and/or when the HRT was reduced. Above results concluded that PVA-Gel addition enhanced the MABR performance.

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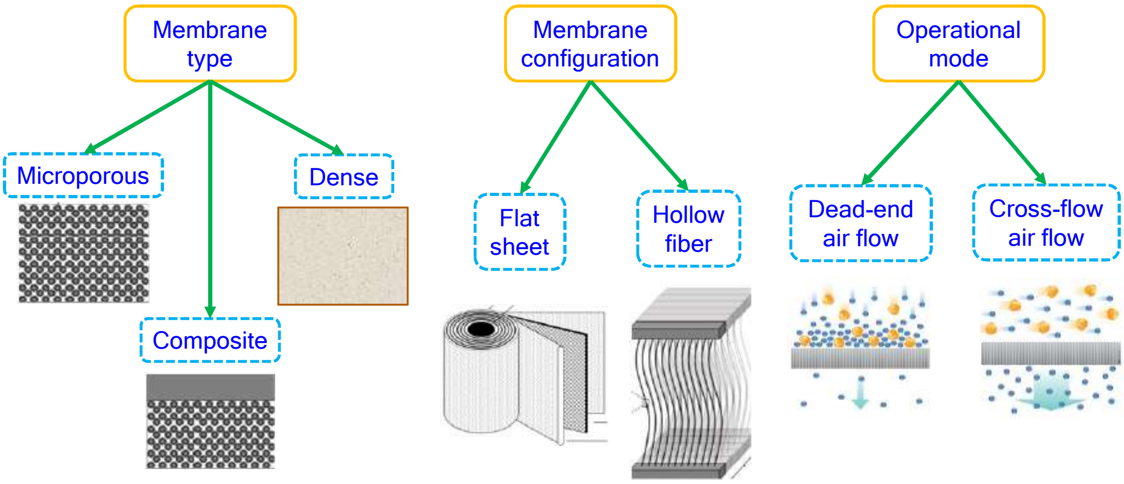
Thank You!

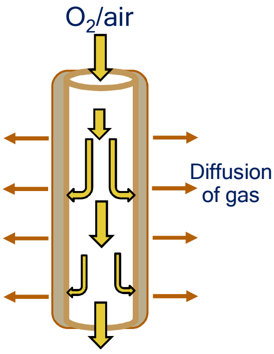
Categorization of MABR



Advantages of MABR over other methods

Biofilm on membrane surface

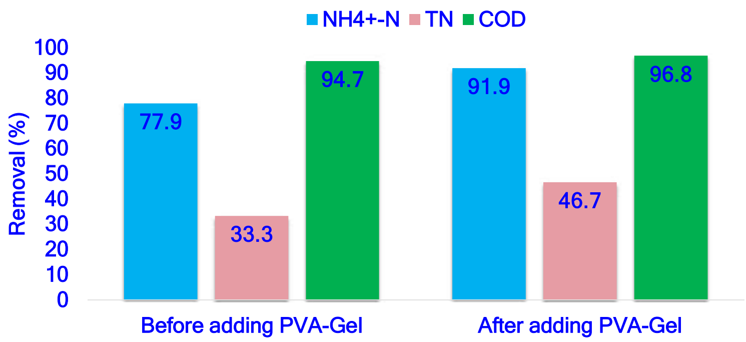
- No need of separate anoxic tank
- No recirculating pump requirement
- Provide increased SRTs
- Reduced footprint



Gas diffusion mechanism

- Higher gas utilisation
- Allow for safe use of flammable gases
- Energy saving (80% saving in energy cost compared to CAS process) (Semmens et al., 2003)
- Air can be delivered at low pressures
- Gas transfer to biofilm can be increased
- Prevent the stripping of volatile organic compounds (VOCs) and greenhouse gases

Removal Comparison With and Without PVA-Gel



Conclusion:

- By the addition of PVA-Gel bio-carriers
  - NH_4^+-N removal increased
  - TN removal increased
  - COD removal was not affected

N removal in wastewater

Bardenpho Process

NH_4^+ —*Nitrosomonas*→ NO_2^-

NO_2^- —*Nitrobacter*→ NO_3^-

NO_3^- —*HDB*→ N_2 (g)

- Need an anoxic tank additional to aeration tank
- Need recirculation

Novel Biotech. Methods

ANNAMOX

SHARON

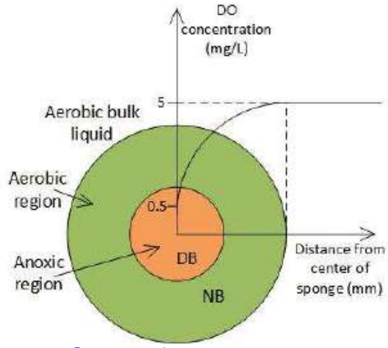
CANON

OLAND

- Mediated by autotrophic microbes
- Effective for wastewaters with very low organic carbon concentrations (COD/N≤1)

(Gopakumar, 2018)

Conventional SND



- Cost saving
- Particularly suitable when treating WW with low COD/N ratios (COD/N≤5)

(Guo et al., 2005)

COD removal in wastewater

Oxidation and synthesis:

CHONS + O_2 + Nutrients —*HB*→ $C_5H_7NO_2$ + CO_2 + NH_3 + by products

Endogenous respiration:

$C_8H_{12}O_3N_2$ + $3O_2$ —*HB*→ $C_5H_7NO_2$+ NH_3 + $3CO_2$ + H_2O

But, in SND:

5 $C_6H_{12}O_6$ + 24 NO_3^- —*HDB*→ 12 N_2 (g) + 24 HCO_3^- + 6 CO_2 + 18 H_2O

MBR for domestic WW treatment

Advantages of MBR over CAS process

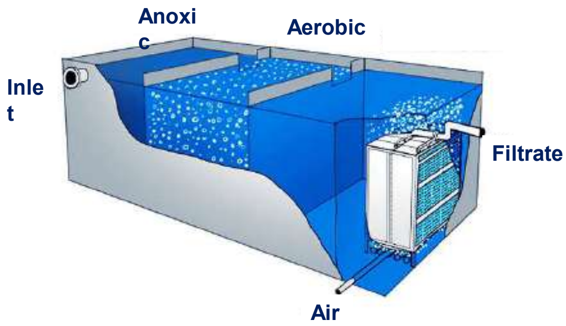
1. Smaller footprint and smaller reactor volume
2. Decreased sludge production
3. Higher effluent quality
4. Low sensitivity to contaminant peaks
5. Removal of most bacteria and virus

But?

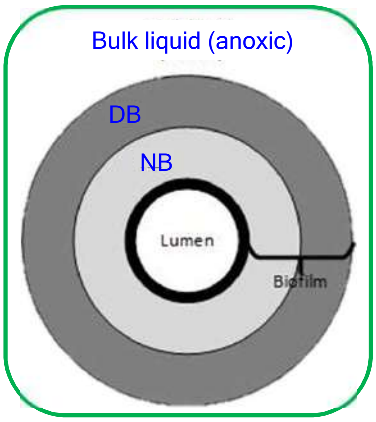
For TN removal

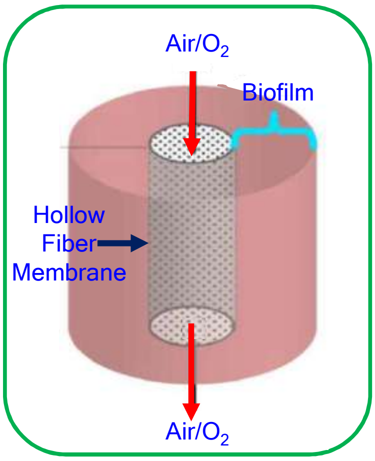
Needs modification

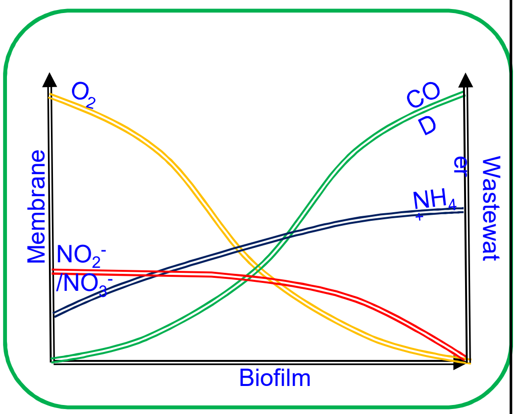
1. Attached-growth system
2. Suspended growth system
3. Anoxic & aerobic compartments



Biofilm Formation On Membrane Surface







NB - Nitrifying bacteria; DB - Denitrifying bacteria

Limitations

Limitations in conventional treatment methods

- High construction cost
- High operation and maintenance cost
- Large footprint

In bardenpho process and using modified MBR

- Difficult to treat low strength domestic wastewater (4 ≤ COD/N ≥ 7)

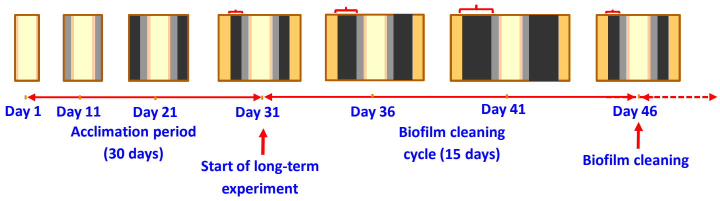
In other N removal techniques except SND

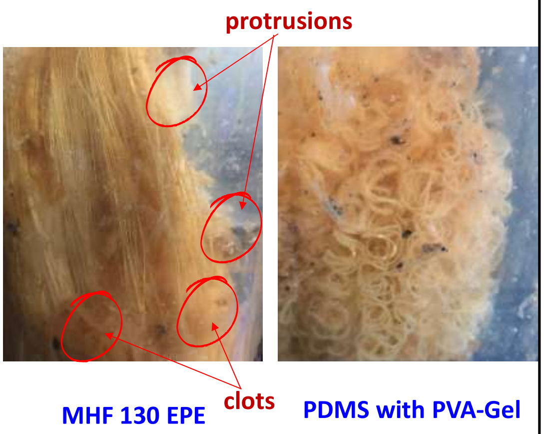
Limitations in MABR

- No standard method to control the biofilm thickness
- Need of HRT higher than 12h to achieve adequate TN removal
- Different studies suggest different COD/N ratio for optimum TN removal
- Low denitrification rate at low HRTs

Additional Benefits of using PVA-Gel Bio-carriers

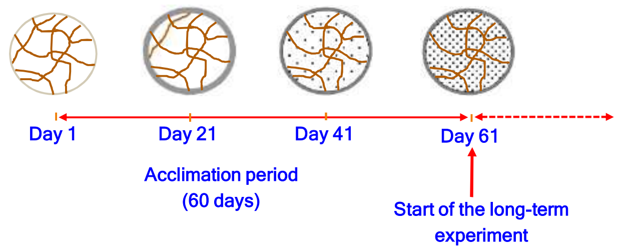
1. Control of biofilm thickness





Additional Benefits of using PVA-Gel Bio-carriers

2. Reduced sludge production



According to PVA-Gel manufacturer,

Generation of excess sludge is low because;

- Proliferation and death of bacteria is almost equal when using PVA-Gel