Theme No: VI Sub topic: Cleaner Production & Emerging Sustainable Practices

Advances in energy efficient technologies for low-strength wastewater treatment

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Abstract

Conventional wastewater treatment plants are major energy sink. Anaerobic treatment of high-strength wastewater has been well studied and proven technology for energy recovery. Challenges lies in the anaerobic treatment of low-strength wastewaters such as municipal wastewater. Wastewater treatment technologies, which either recover energy in different forms from wastewater or energy efficient have attracted more attention. Apart from anaerobic treatment, algal technology has become more popular for municipal wastewater treatment and energy recovery in the form of biodiesel. Microbial fuel cells, which generate electricity from wastewater while treating the same, are also gaining much more attention. Anammox (Anaerobic ammonia oxidation) has also been applied in mainstream as an energy efficient technology for municipal wastewater treatment. The current paper reviews the advances in these energy efficient technologies for the treatment of low-strength wastewater. The paper also discusses the limitations of these technologies, which need to be addressed for the successful application of these technologies in treating low-strength wastewaters.

Keywords: Anaerobic treatment; Sewage; Energy recovery; Anammox; Microbial fuel cells; Algal biofuel

Advances in energy efficient technologies for low-strength wastewater treatment

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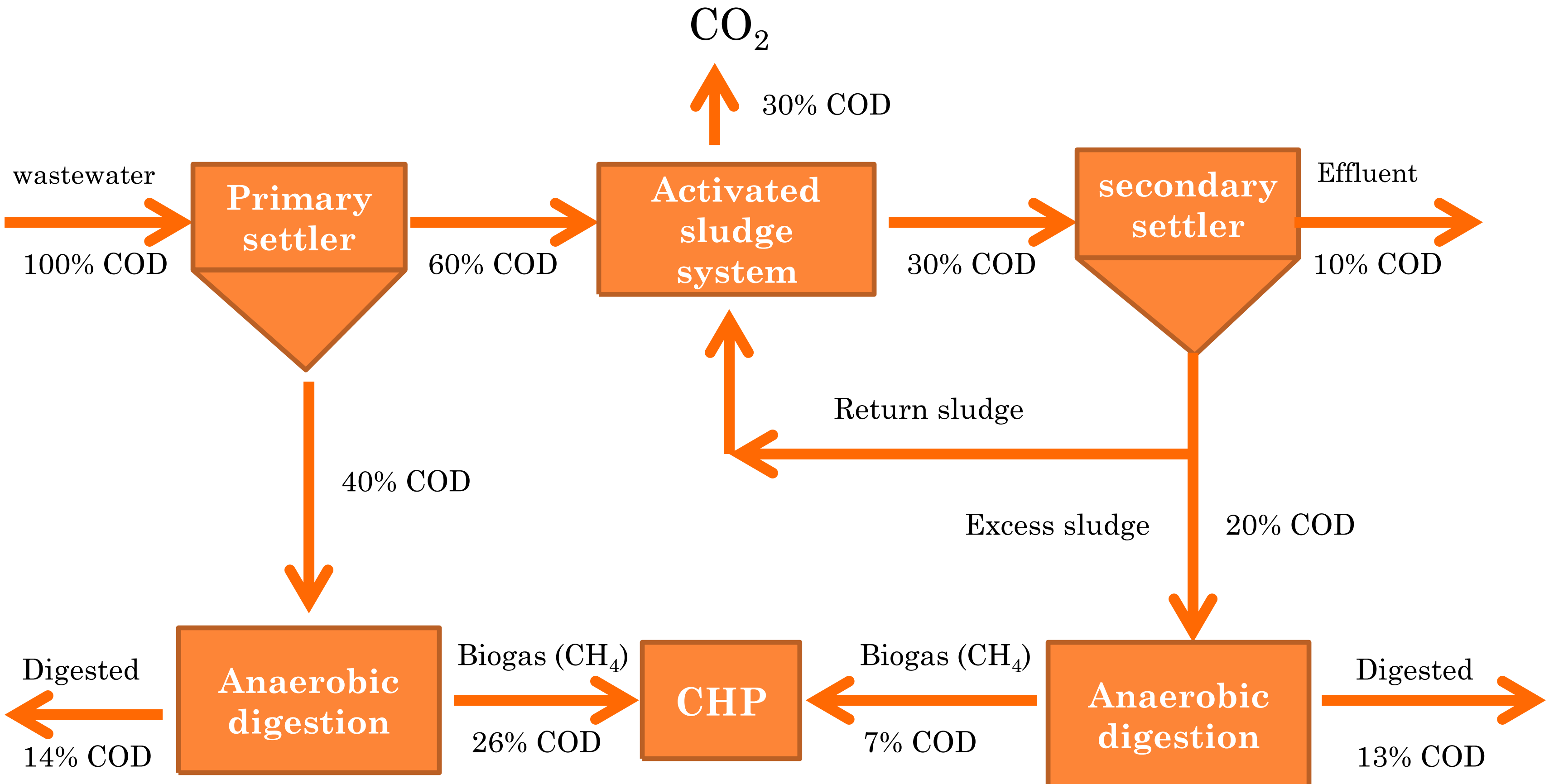
Conventional treatment of low-strength wastewater

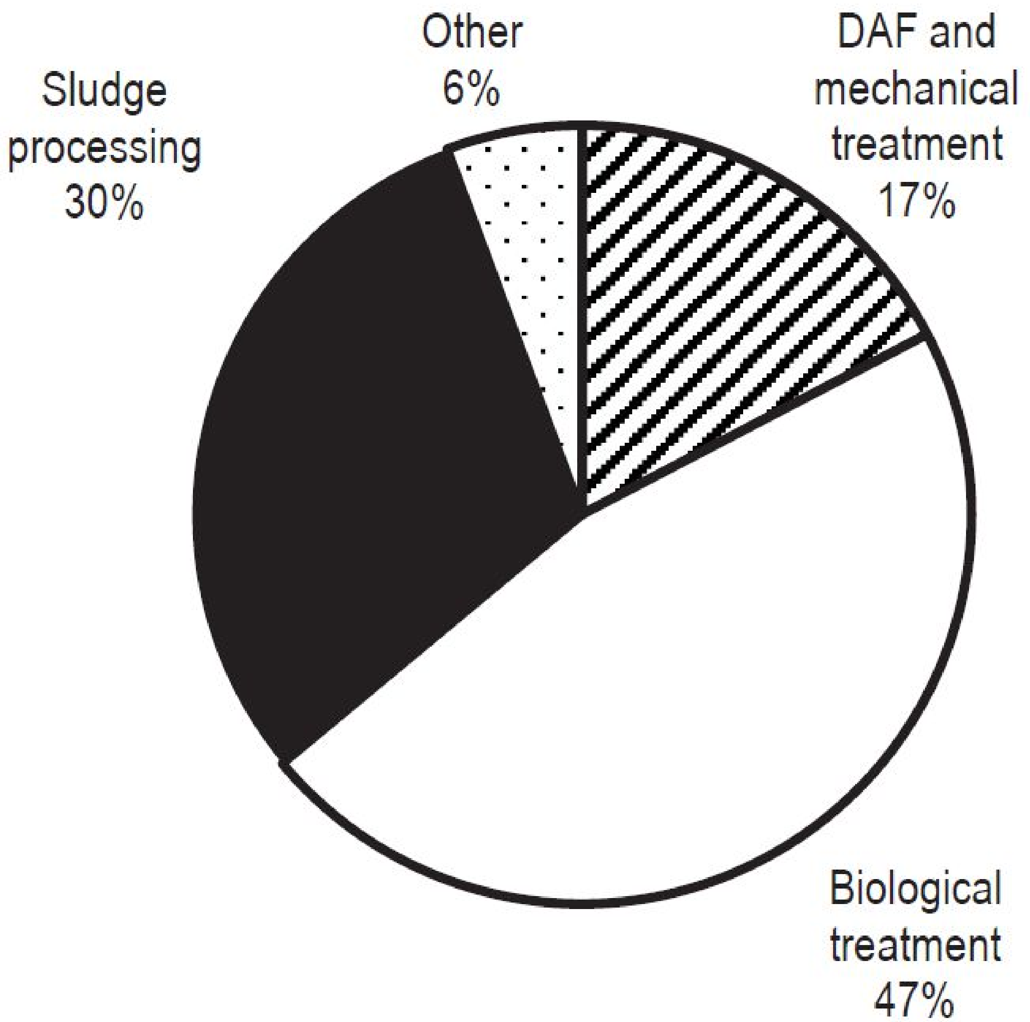


ENERGY CONSUMPTION IN WWTPS

- The energy consumption is normally in the range of 0.3 to 0.6 kWh /m^3 of wastewater treated with an average of 0.45 kWh/m^3 equivalent to 1620 kJ/m^3.

Country	Treatment process	Energy consumption (kWh/m^3)	References
USA	CAS	0.78	US EPA & US ED 2007
Edmonton Capital Region (Canada)	CAS	0.33	Lidkea (2007)
Calgary Fish Creek (Canada)	CAS	0.52	Lidkea (2007)
Austria	CAS	0.30	Jonasson (2007),
Sweden	CAS	0.47	Jonasson (2007),
Belgium	CAS with membrane bioreactor	0.8-1.2	Fenu 2010
Belgium	CAS with tertiary membrane filtration and	0.59	Fenu 2010

Energy usage characteristics of Bielmlek (Poland) WWTP



Dąbrowski et al. (2016) J Ecological Eng. 17, 73-78.

PARADIGM SHIFT IN RECENT PAST

- Though the conventional aerobic treatment technologies like the activated sludge are highly efficient yet these are energy intensive.
- We need energy efficient technologies
- In the past, wastewater was a "**problem**" but now it is considered as a "**resource**"

Energy efficient technology for wastewater treatments

Energy recovery technologies

- Anaerobic treatment
- Microbial Fuel cells
- Algal Technology

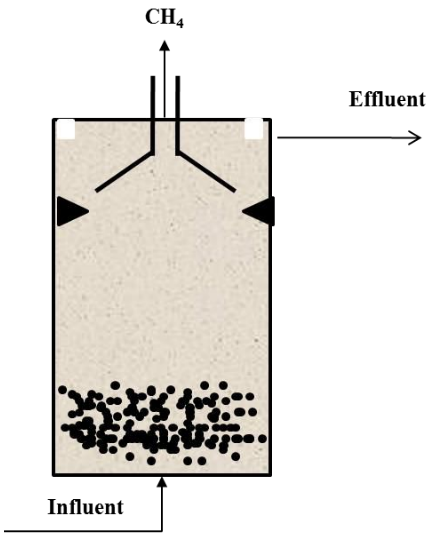
Energy efficient nitrogen removal

- Anammox

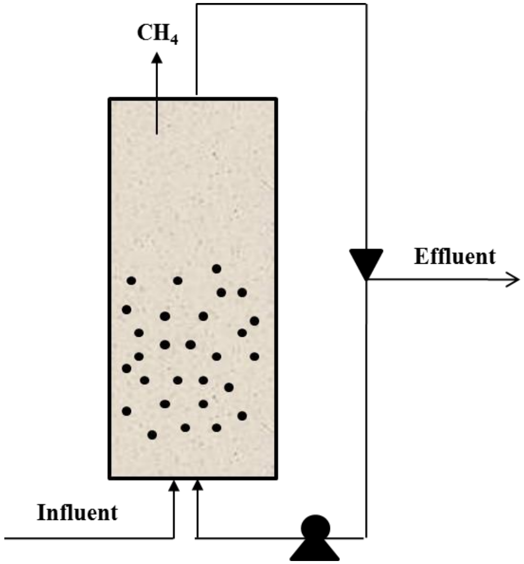
Anaerobic treatment

- Upflow anaerobic sludge blanket (UASB)
- Anaerobic fluidized bed reactor (AFBR)
- Anaerobic membrane reactor (AFMBR)
- Two stage AFBR+AFMBR or SAF-MBR

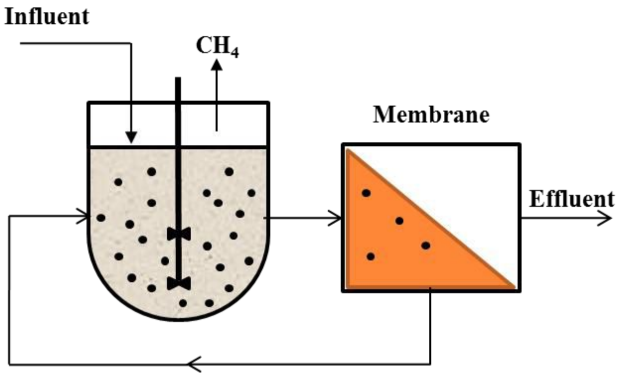
Reactors for anaerobic treatment



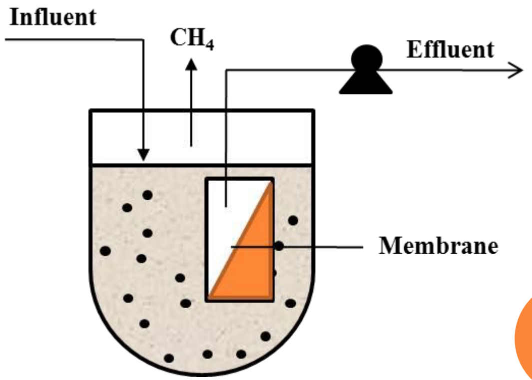
UASB



AFBR

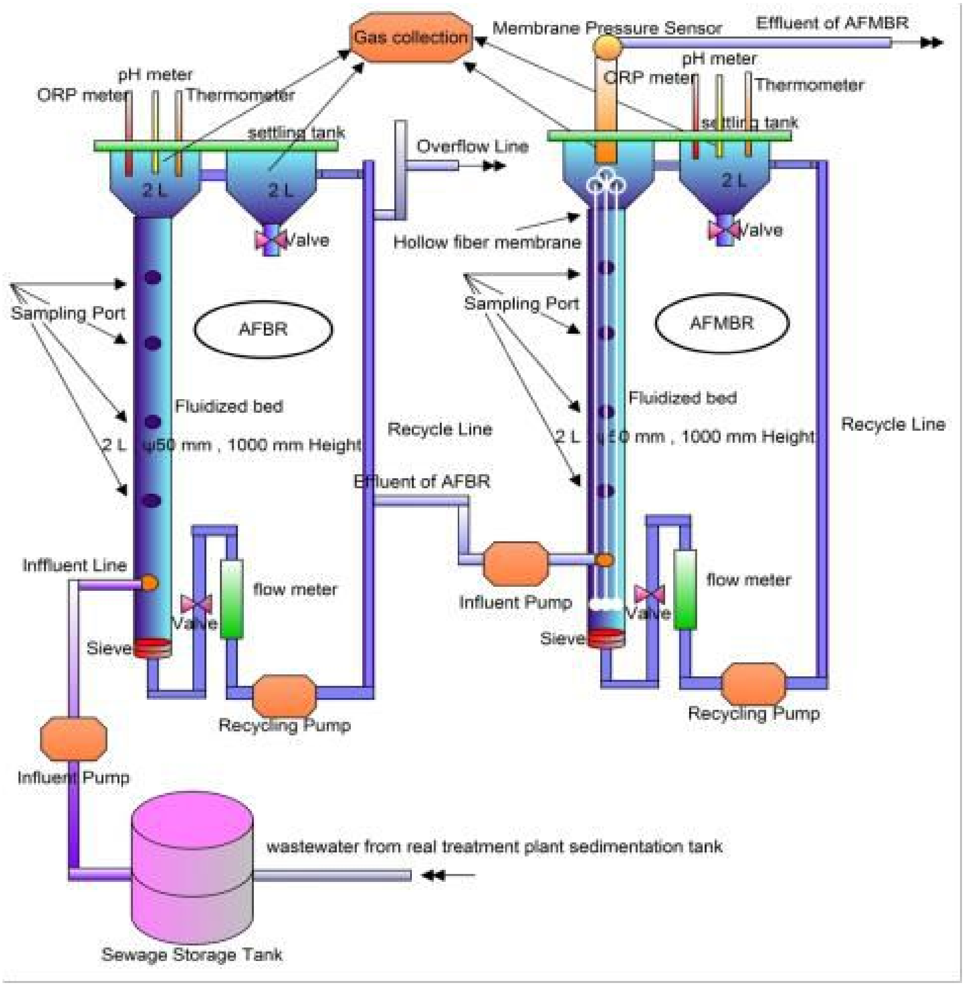


Sidestream AMBR



Immersed AMBR

Reactors for anaerobic treatment

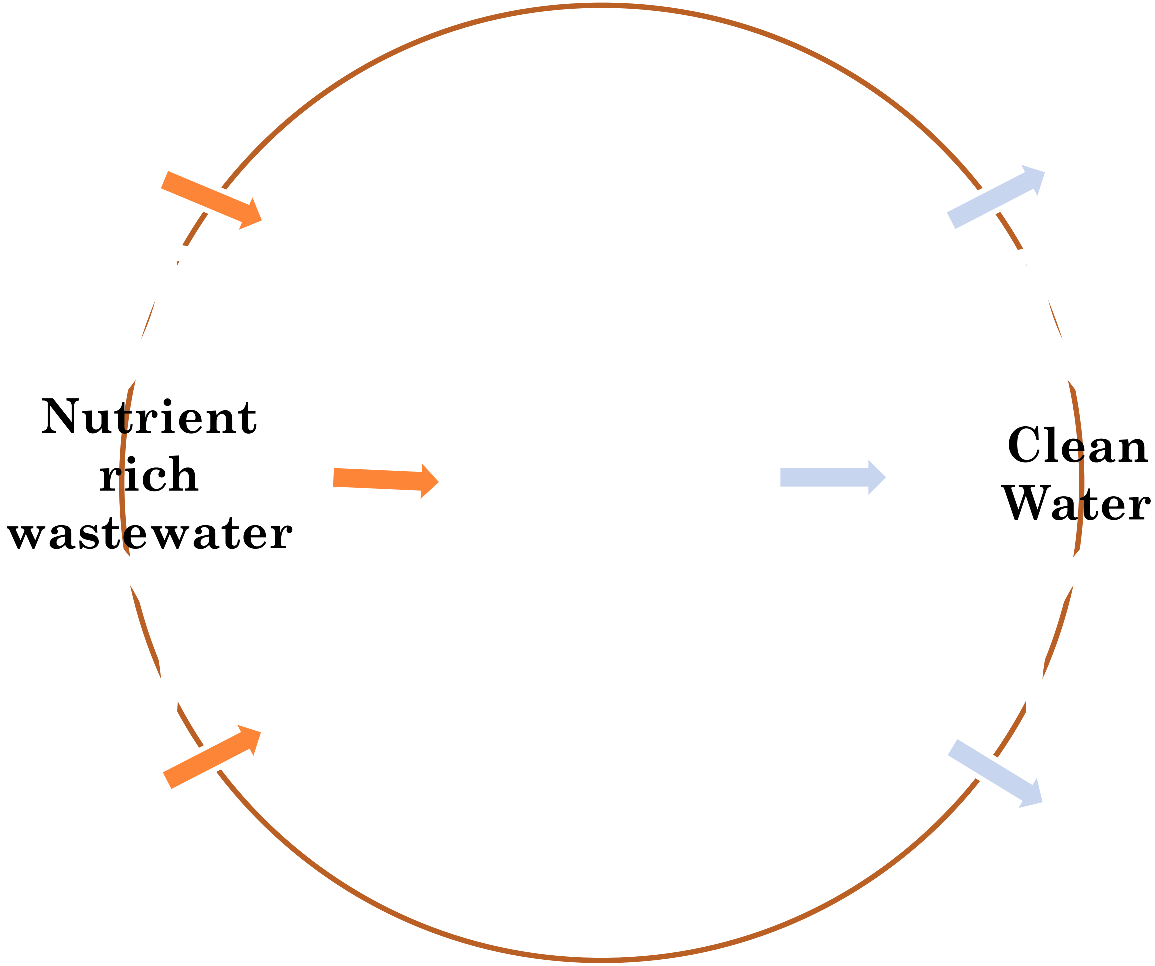


AFBR-AFMBR (Dutta et al., 2014)

Limitations for anaerobic system

- Low methane production rate for low strength wastewater.
- Performance decrease for temperature lower than 10ºC.
- Nitrogen and other nutrient removals are less.

- Microalgae referred to as "third generation” biofuel are oxygen-releasing photosynthetic organisms with a simple cell having no roots, stems, or leaves.



Microalgae and municipal wastewater

Integrating microalgae at MWWTP offers many benefits:

- Provides a suitable growth medium
- remove heavy metals (Kumar et al. 2015)
- Fix CO_2(1 kg of dry algal biomass utilizes about 1.83 kg of CO_2 Chisti 2007) from the atmosphere during photosynthesis and release the oxygen thus solving the problem of global warming
- As microalgae act as tiny aeration devices, they reduce the intensive oxygen demand needed for nitrification in WWTPs.
- Have the ability to remove nutrients (Nitrogen, Phosphorus and other nutrients), heavy metals, toxic substances (both organic and inorganic) present in wastewater.
- Grow rapidly and do not need land for cultivation
- Generates value added components i.e. after lipid extraction the protein-rich residue can be used for feeding the animals and fertilizing crops (Cai, Park, & Li, 2013).

Thus combining microalgae with MWWTPs have resulted in refreshed consideration of the need and benefits of microalgae over traditional nutrient removal technologies.

Limitations

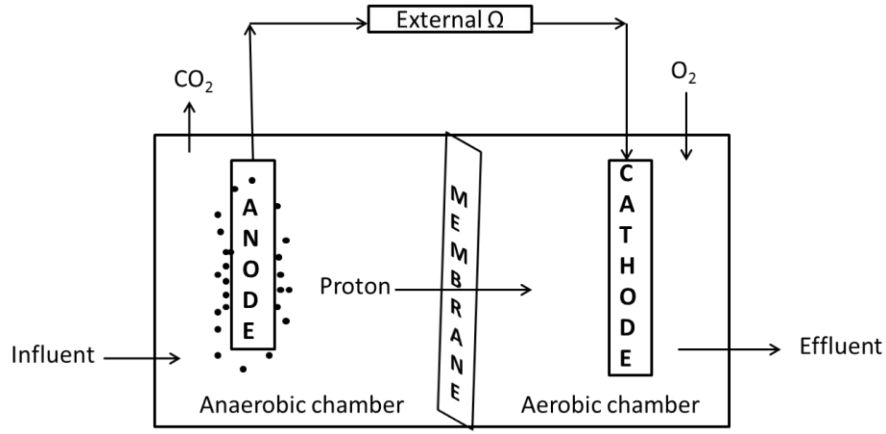
Pilot-scale application of algae still faces many challenges as :

- A cost-effective harvesting system needs to be developed.
- Further research is needed to identify better algal strains to match the target wastewater.

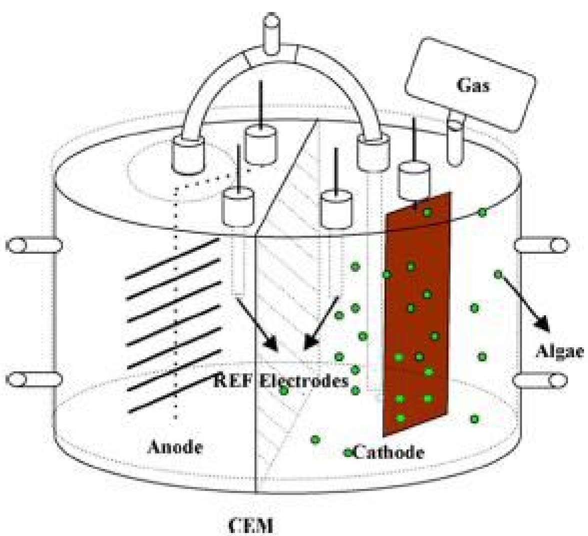
MICROBIAL FUEL CELLS

Types of MFCs

- Two chamber MFC
- Single chamber MFC
- Air cathode MFC
- Photo –MFC
- Algal assisted MFC
- Microbial carbon capture cell

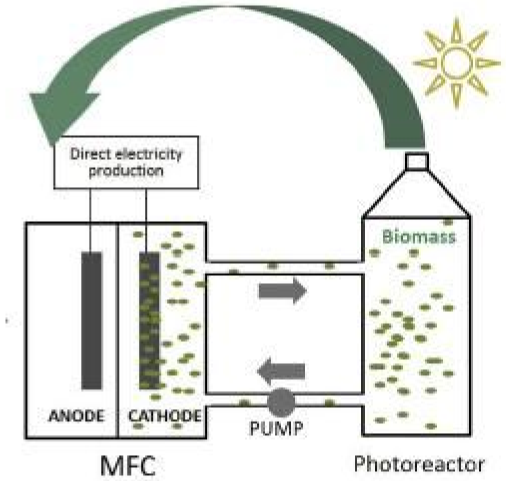


Dual chambered MFC

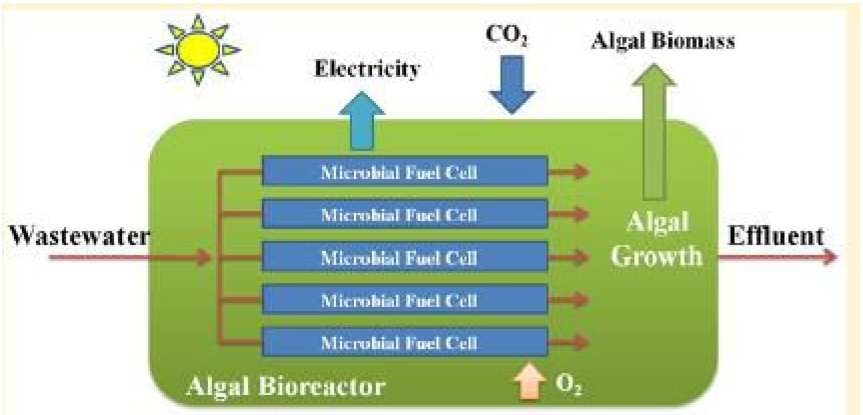


Microbial carbon capture cell (Wang et al., 2010)

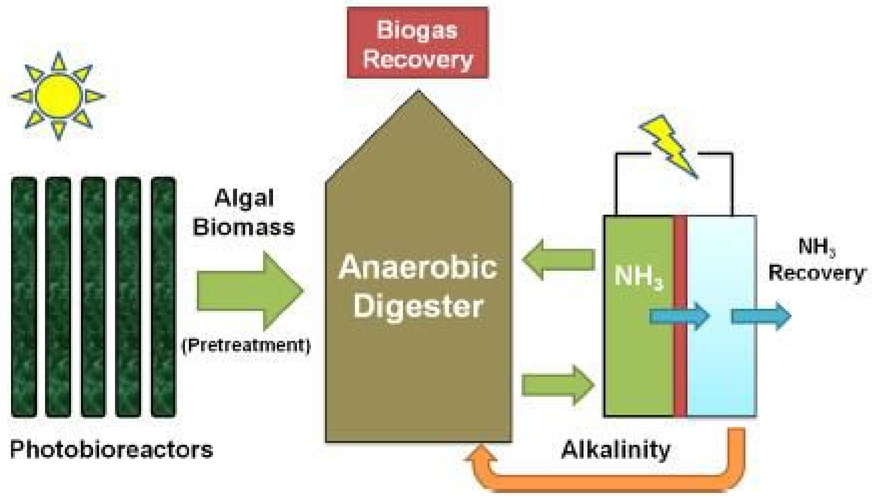
Combined type of reactor designs



Algae grown MFC (Gajda et al., 2015)



Integrated Photo-Bioelectrochemical System (Xiao et al., 2012)



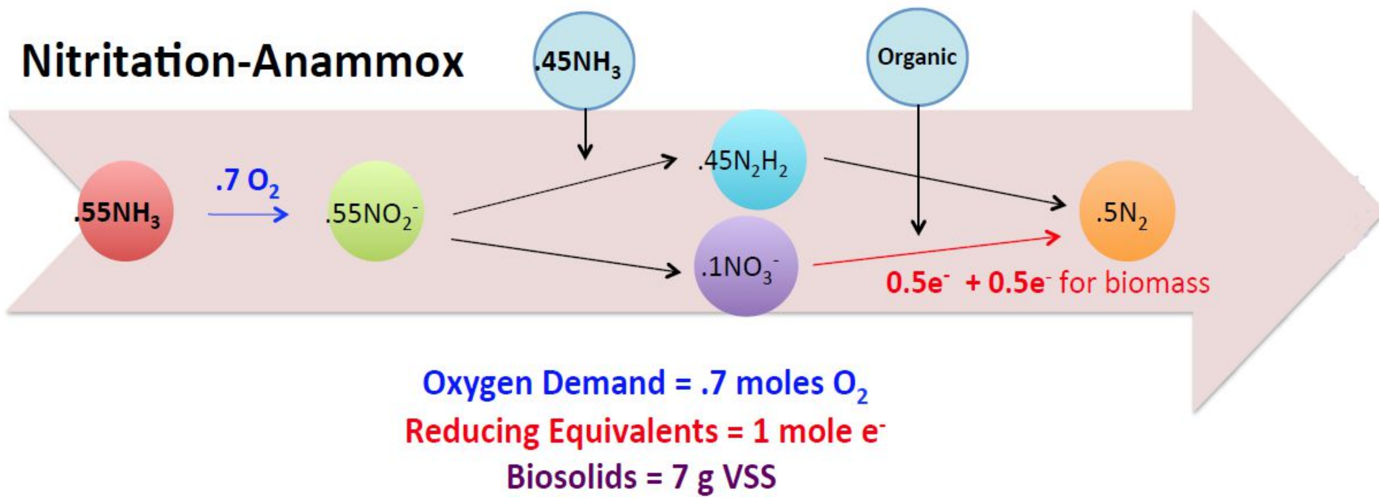
A closed loop reactor setup consisting of an algal growth unit, an AD and an MFC (Schamphelaire and Verstraete 2008)

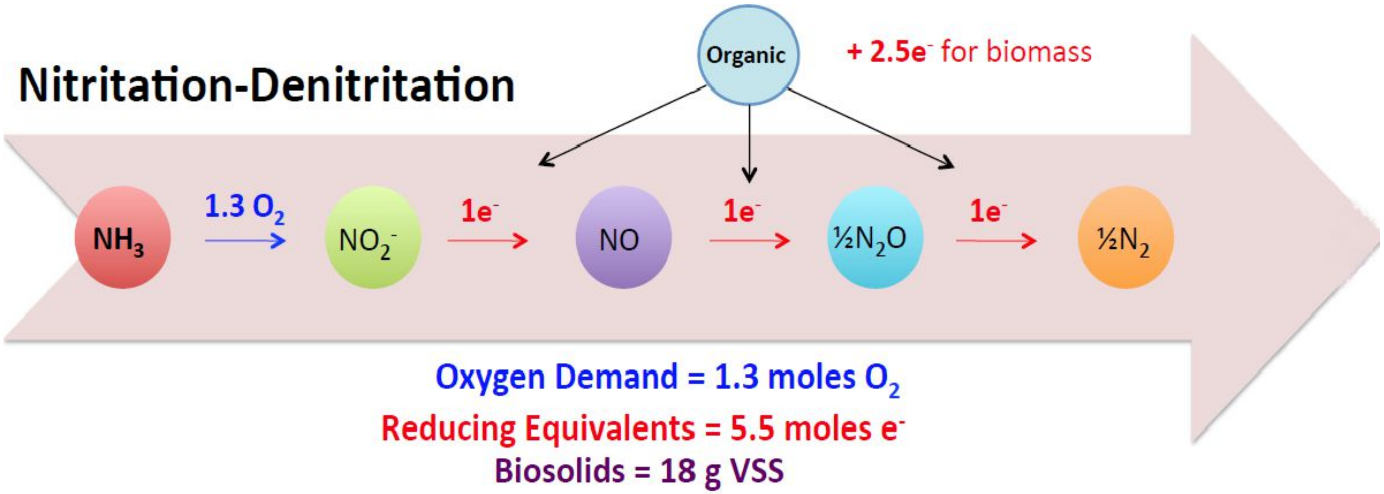
Anammox as energy efficient technology for nutrient removal

Innovative anaerobic treatment and energy saving technology like nitritation-anammox for N removal is considered attractive and promising than the conventional nitrification and denitrification process (Gao and Tao 2011).Thanks to the technology as:

- The need to add an electron donor can be avoided
- 60% reduction in power consumption
- Production of surplus sludge is minimized by 80%, thus resulting in significant savings in operation costs. (Abma et al. 2007)

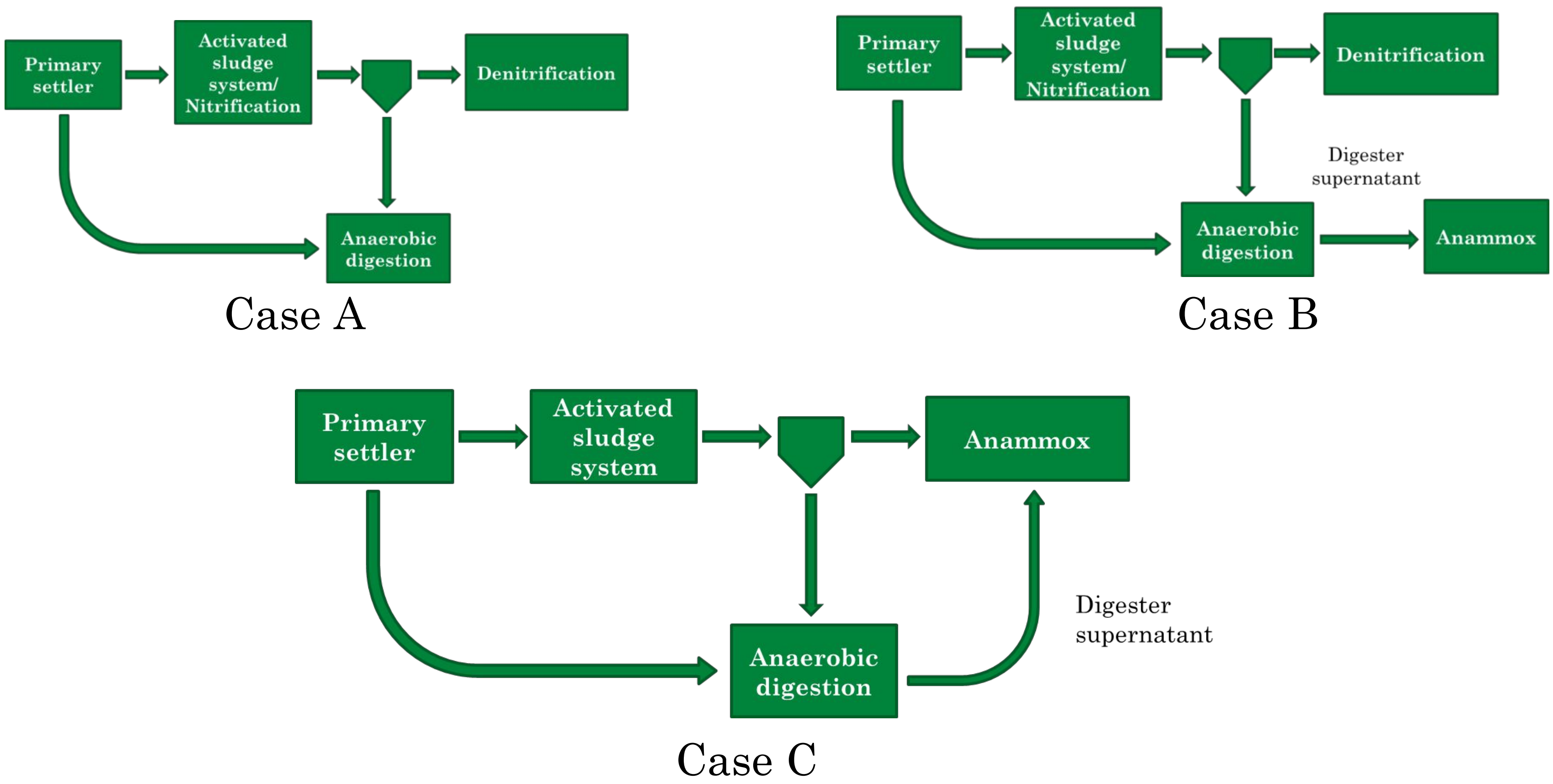
The Anammox is a novel autotrophic biological nitrogen removal process that converts ammonium to dinitrogen (N_2) gas in the absence of oxygen with nitrite (NO_2) as an electron acceptor (Kartal et al. 2013)





Adopted from Gao et al.(2014) *Environ. Sci.: Processes* , 16, 1223-1246

ANAMMOX AS ENERGY SAVING TECHNOLOGY FOR NUTRIENT REMOVAL



(Case A) Conventional treatment;
(Case B) Conventional treatment, with anammox used for treatment of digester effluent;
(Case C) Optimized treatment, with anammox in the full main water line.

Oxygen and Energy need	Mass Flux (g/p.d)			Energy (Wh/p.d)		
	Case A	Case B	Case C	Case A	Case B	Case C
Aeration for COD removal	40	30	15	-40	-30	-15
Aeration for nitrogen removal	22	22	16	-22	-22	-16
Pumping/mixing energy				-20	-20	-15
Methane-COD and electrical energy production from biogas	30	40	55	+38	+51	+70
Net Energy				-44	-21	+24

Units: Mass flux, grams per person per day (g p^{-1} d^{-1}); energy, Watthours per person per day (Wh p^{-1} d^{-1}).

Adopted from Kartal et al. (2010) *Science 328, 702*

Conclusion

- The energy self-sufficient WWTPs are definitely feasible, Energy-efficient technologies are being applied to two platforms
  - The side-stream sludge digestion process
  - Mainline treatment process
- These cutting-edge biotechnologies, in combination with low-energy nutrient-removal/recovery processes, offer an exciting opportunity to realize truly sustainable municipal wastewater treatment.
- There are still many challenges to construct these self-sufficient WWTPs, particularly in developing countries. More efforts are needed in terms of technology, costs, scale of operation and environmental protection issues.