13th IWA Specialized Conference on Small Water and Wastewater Systems

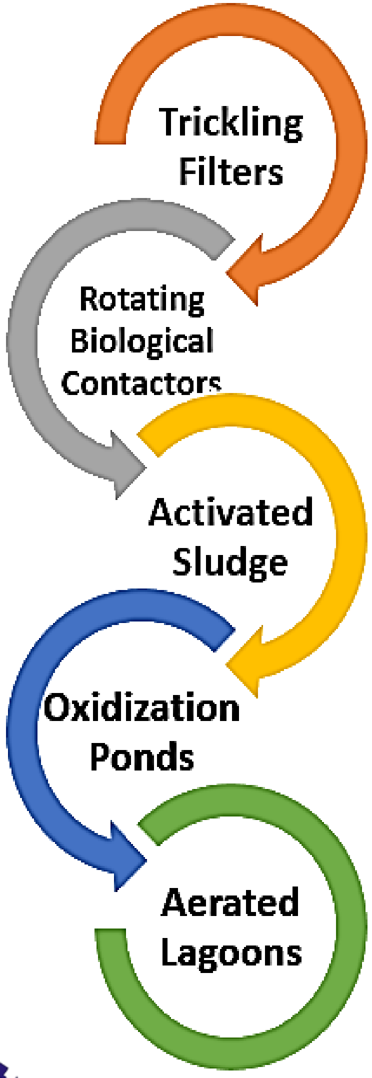
5th IWA Specialized Conference on Resources-Oriented Sanitation

Topic: Advances in wastewater treatment by combined microbial fuel cell-membrane bioreactor (MFC-MBR)

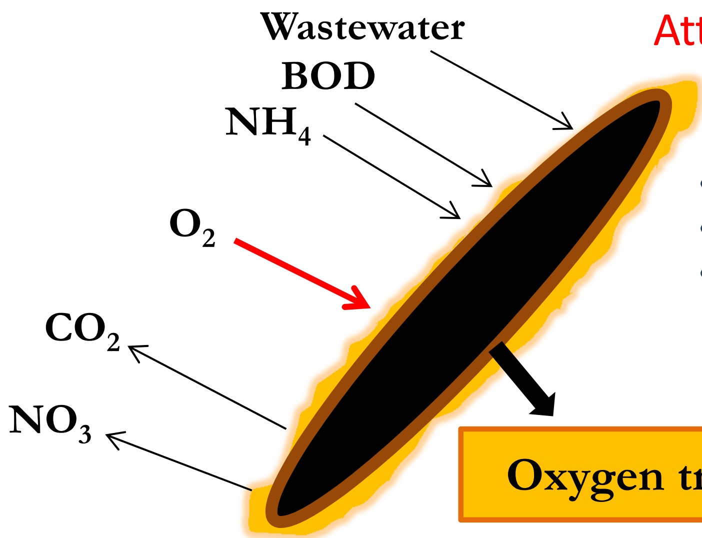
Sreemoyee Ghosh Ray
Gourav Dhar Bhowmick
Prof. Makarand M. Ghangrekar
Prof. Arunabha Mitra

भारतीय प्रौद्योगिकी संस्थान खड़गपुर
Indian Institute of Technology Kharagpur

Commonly Used Aerobic Biological Wastewater Treatment Processes



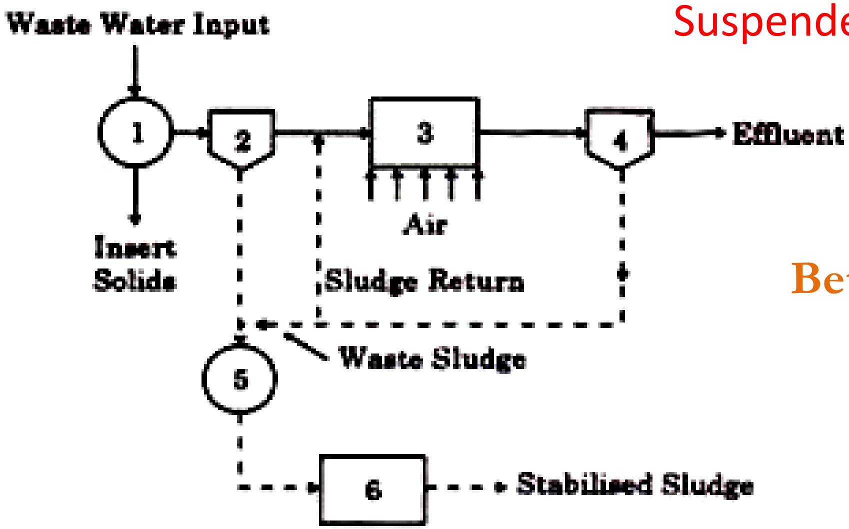
Attached growth process



- Aerobic respiration pathway
- Bio-oxidation
- Nitrification

Oxygen transfer limitation

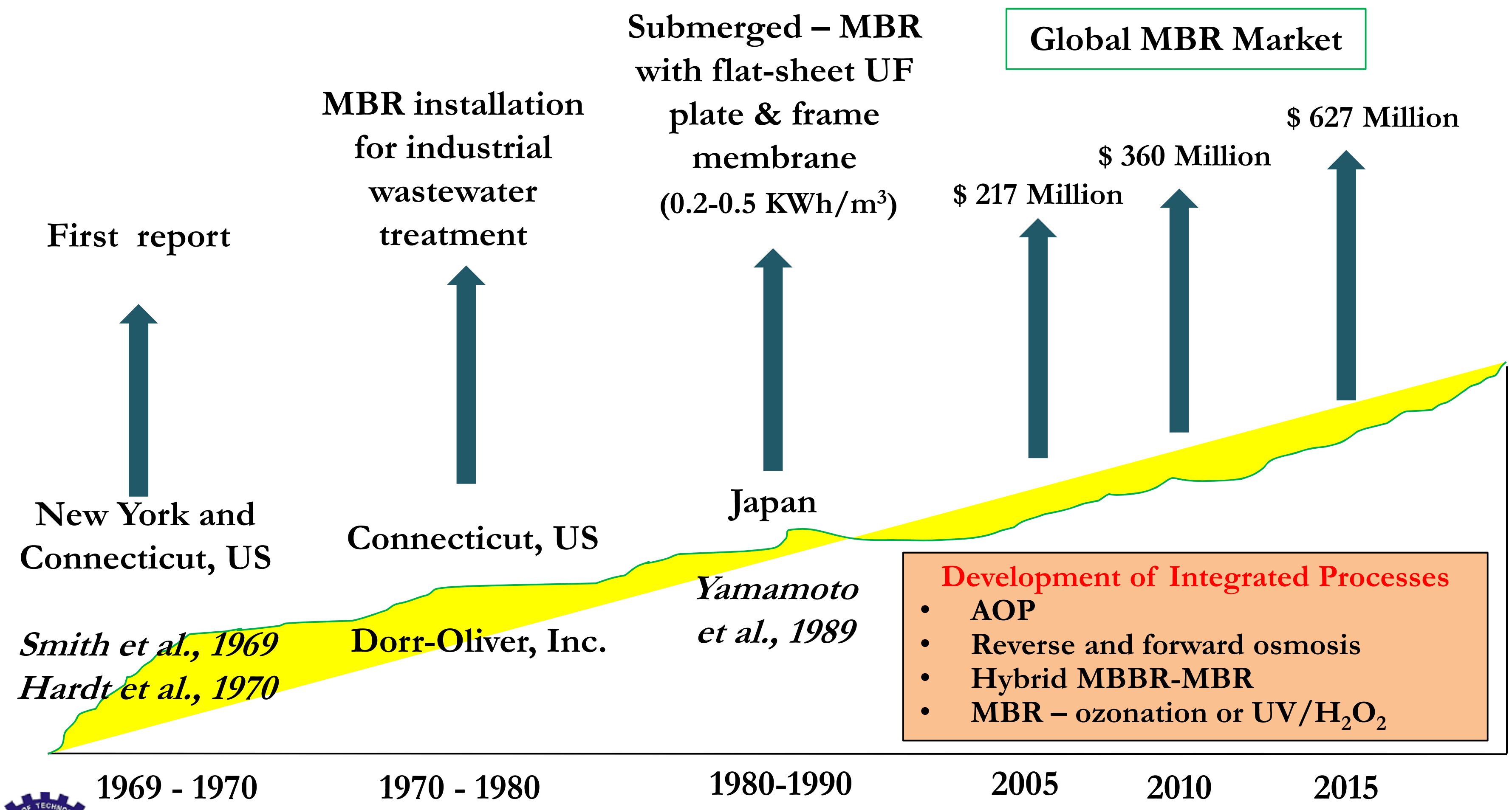
Suspended growth process



Better treatment efficiency

Membrane bioreactor (MBR) Technology

Biological – ASP + Membrane Filtration



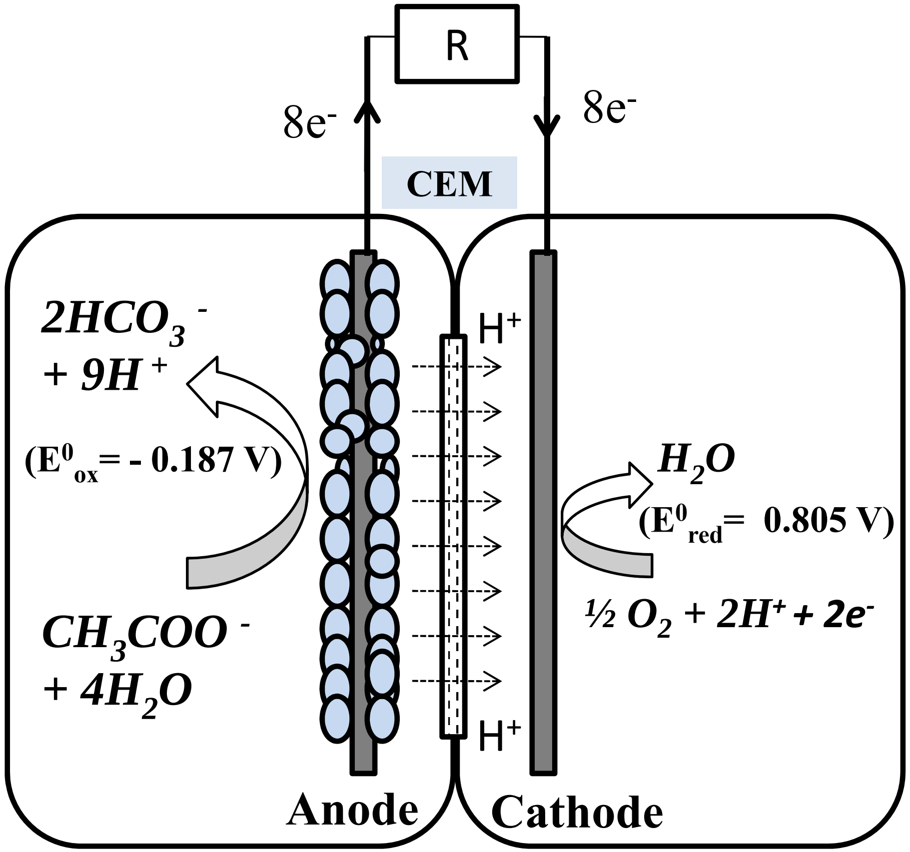
MBR technology involves high energy-consuming process

Energy consumption of MBR can be lowered by integrating it with Microbial Fuel Cell (MFC) technology

Conversion of bio-chemical energy to electrical energy

Bio-electricity – An Alternative and Clean Energy

- How much electrical energy can be generated?
- Can we provide an efficient treatment?
- Can low-cost sustainable development of MFC-MBR technology be achieved?



Microbial Fuel Cell (MFC)

Recent advances in MFC-MBR processes

Completely anaerobic process

- **Electrochemical – MBR**

  Wang, 2013 – *Sci. Rep.*
  Ge, 2013 – *J. Chem. Technol. Biotechnol.*
  Wang, 2012 – *Appl. Energy*

- **Up-flow integrated air-cathode MFC-MBR**

  Wang, 2013 – *Chem. Eng. Technol.*

Lower energy consumption

Combination of anaerobic – aerobic process

MFC – Biocathode MBR

Wang, 2014 – *Bioresour. Technol.*

Consumption of electrical energy to develop MFC-based biosensors

Aim of our research

Development of two-stage continuous process of combining MFC with MBR treatment technology for a highly-efficient and reliable wastewater treatment

- For treatment of organic wastewater, having COD of 3 g/l
- To achieve better treatment efficiency in terms of organic matter removal
- Recovery of high quality reusable effluent

Reactor fabrication and operating principle

MFC

Parameters	Operating conditions
Working volume	1.5 l
Electrode material	
Anode	Carbon felt (untreated)
Cathode	C/TiO_2 suspension
Inoculum	Mixed anaerobic sewage sludge
Substrate	Synthetic wastewater – Sucrose as carbon source Jadhav & Ghangrekar, 2009 (*Bioresour. Technol.*)
Substrate conc.	3 g COD/l
HRT	2 days

Aerobic MBR

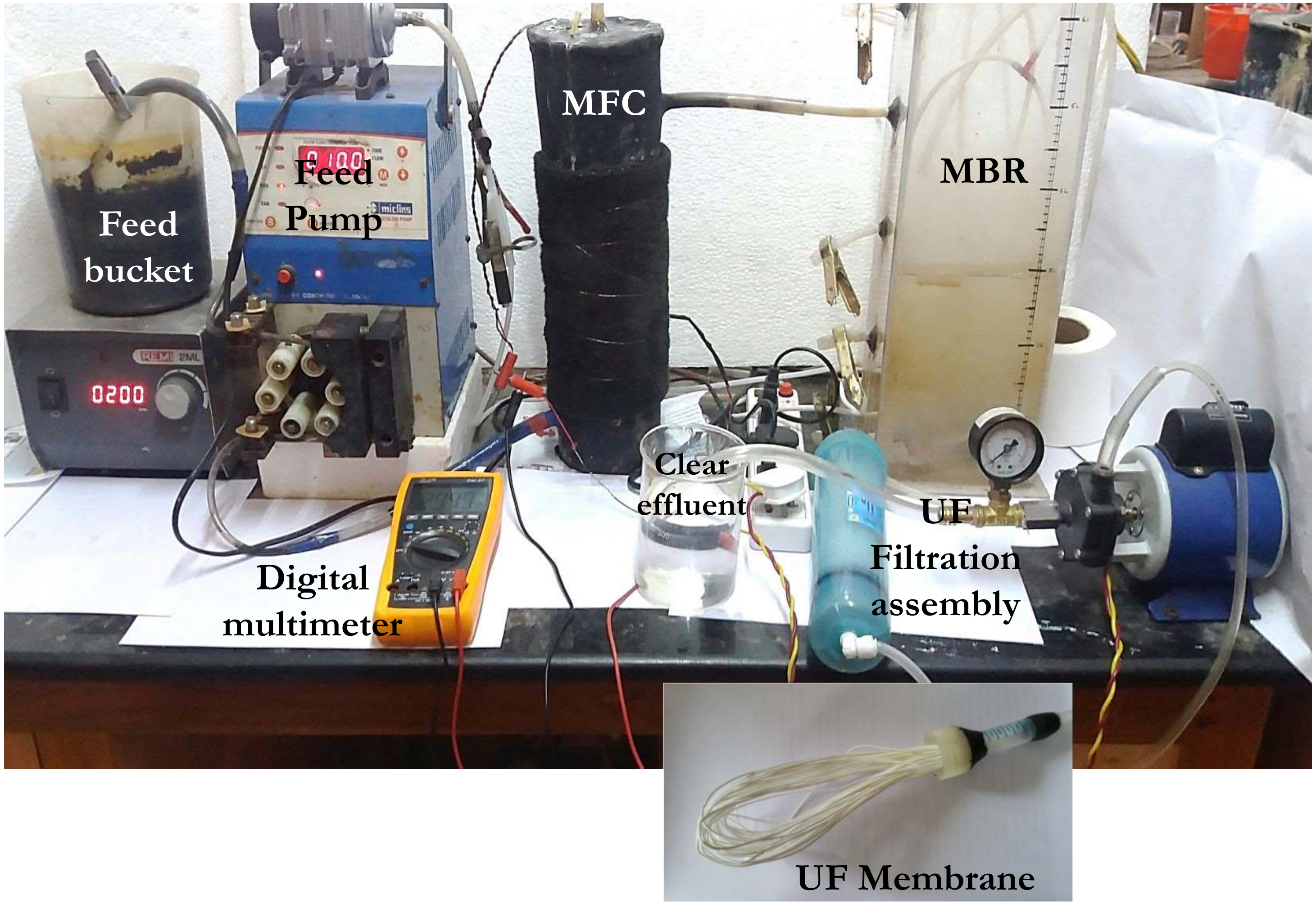
Parameters	Operating conditions
Working volume	1 l
MLSS	7.09 ± 0.48 g/l
F/M	0.08 kg COD/kg MLSS. day
HRT	10 h
Inoculum	Aerobic pond sediment
Substrate	MFC effluent
Membrane filtration	Hollow-fibre Polysulfone-made UF membrane (pore size 80 nm, OD 1 mm and ID 0.8 mm)
Membrane area	300 cm^2 /l
Permeate flux	38 $l/m^2.h$

Electrochemical monitoring, polarization study and determination of coulombic efficiency (Logan, 2008 – John Wiley & Sons Inc.)

Total and soluble COD, MLSS, MLVSS, TKN and alkalinity (APHA 1998)

Bench-scale working model

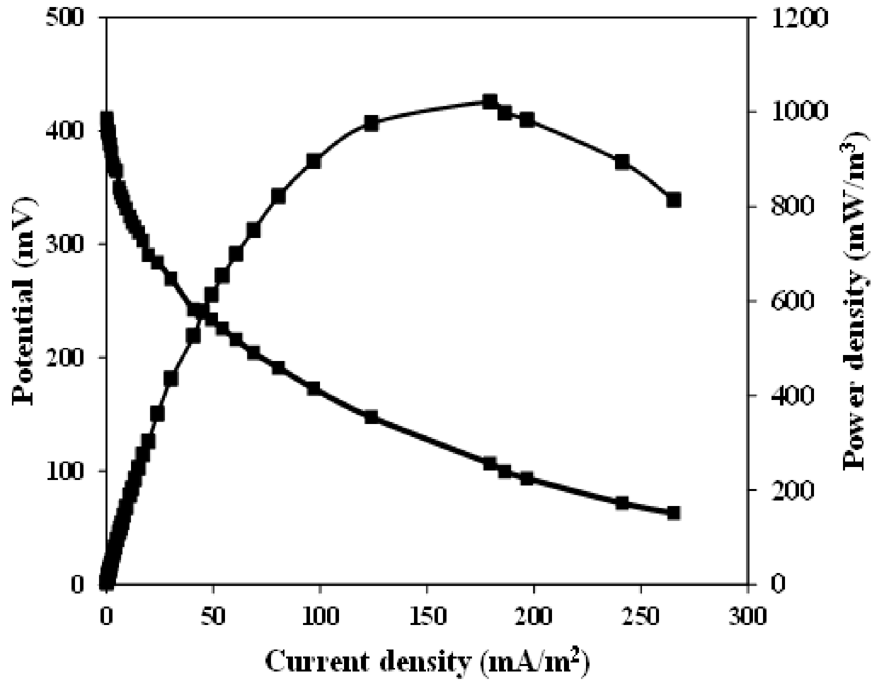
Two-stage wastewater treatment process combining microbial fuel cell and aerobic membrane bioreactor –



Results..

Generation of bio-electricity in MFC

Parameters	Responses
Open circuit potential	536 ± 25 mV
Working potential (100 Ω)	260 ± 12 mV
Power density	1.021 W/m^3
Internal resistance (Whole cell)	17.8 Ω
CE	4.35 %



Polarization and power curves for MFC

Treatment of wastewater in MFC

The COD removal efficiency of **78.4 ± 2.14 %** was observed during MFC treatment. The total COD concentration of MFC effluent was **0.71 ± 0.04 g/l**.

Treatment of MFC-effluent in MBR with submerged UF membrane

Parameters	Wastewater (MFC reactor influent)	MFC reactor effluent	MBR effluent (Permeate)
Total COD	3.02 (0.03)	0.71 (0.04)	-
Soluble COD	2.65 (0.02)	0.59 (0.03)	0.04 (0.003)
TKN	0.31 (0.05)	0.147 (0.02)	0.010
TS	3.67 (0.05)	5.09 (0.08)	-
TSS	-	-	< 0.005
MLVSS	NA	0.9 (0.02)	ND
pH	7.53 (0.14)	7.31 (0.11)	7.4 (0.1)

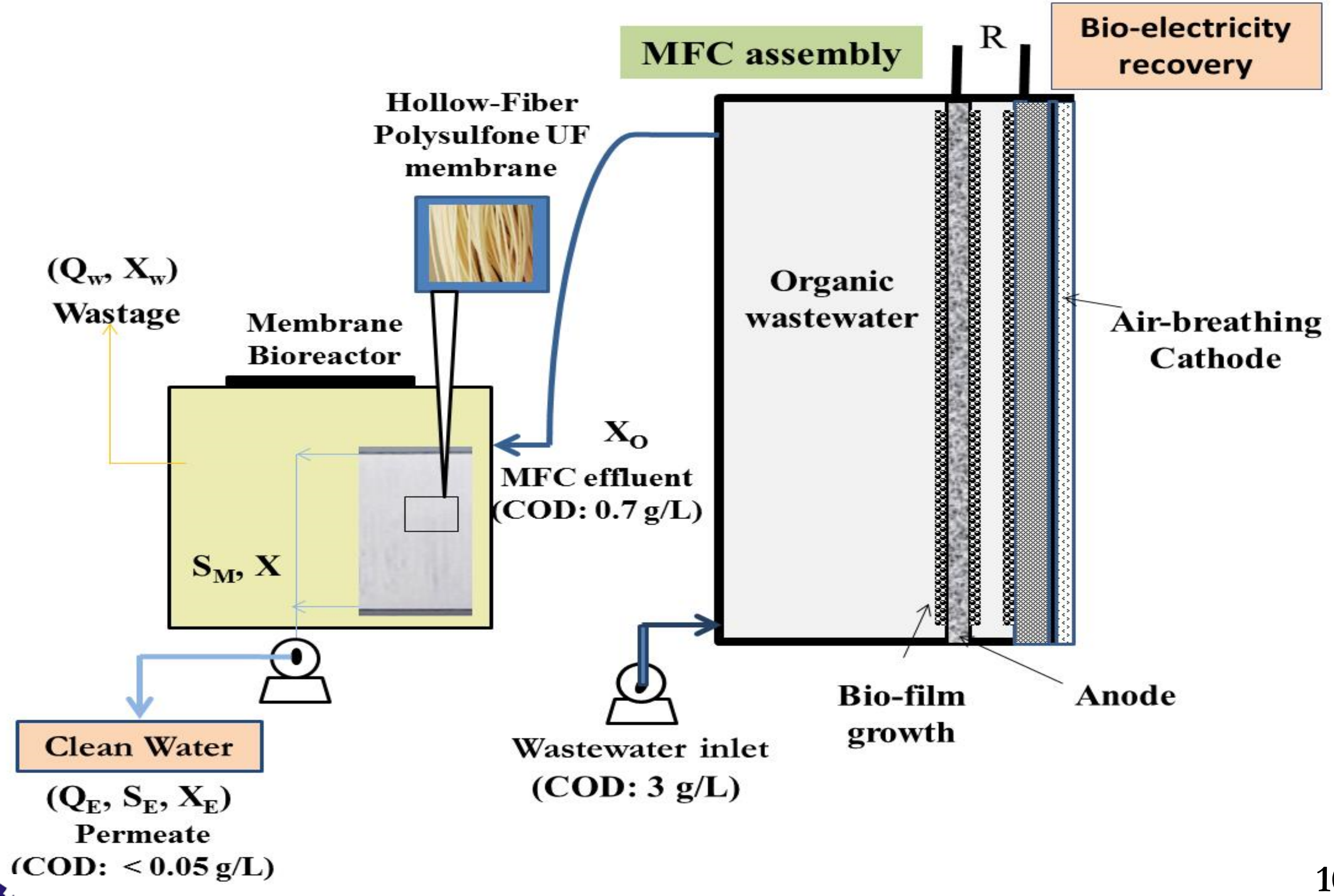
[a] All units are in g/L, except pH; numbers in the parenthesis are standard deviation
NA= Not applicable: ND= Not detectable

Characteristics of effluent at different stages of MFC-MBR treatment

Organic removal efficiency in combined MFC-MBR process

Soluble COD, TKN and SS removal efficiency was **98.49 ± 0.28 %, 96.77 ± 0.12 %** and **99.75 ± 0.18 %**, respectively.

Analysis of Bio-kinetic Parameters of MBR



Kinetic Equations and Results

Monod equation for biomass growth rate: $\mu = \mu_m \frac{S}{K_s+S}$

The rate of change of biomass in MBR: $V.\frac{dX}{dt} = \mu XV - k_d.XV - Q_wX - Q_EX_E$

At steady state condition, $dX/dt = 0$: $\mu = k_d + \frac{Q_w}{V} + \frac{Q_E}{V}.\frac{X_E}{X}$

Sludge retention time, $SRT\ (\theta_c) = \frac{VX}{Q_wX + Q_EX_E}$

Hence, $\mu = k_d + \frac{1}{SRT}$

Thus, the final equation for substrate utilization: $S = \frac{K_s\left(\frac{1}{SRT}+k_d\right)}{\mu_{m-}\left(k_d+\frac{1}{SRT}\right)}$ The substrate balance equation to demonstrate the expression for biomass generation in MBR:

$$X = \left[\frac{Q(S_0-S)-S_E.Q_E}{\left(k_d+\frac{1}{SRT}\right)}\right]\frac{Y}{V}$$

- **The SRT was calculated as 15 days.**
- **Endogenous decay constant (k_d) and sludge-yield coefficient (Y) was calculated as 0.07 d^{-1} and 0.216 g VSS/g of COD, respectively.**

Summary..

- **How much electrical energy can be generated?**

Authors	Anode	Cathode	Maximum power density (W/m^3)
Wang, 2013 (*Water Res.*)	Graphite rod	Stainless steel mesh	1.43
Ge, 2013 (*Sci. Rep.*)	Carbon brush	Carbon cloth coated with 10% Platinum (Pt)	2
Li, 2014 (*J. Chem. Technol. Biotechnol.*)	Carbon cloth	Carbon cloth coated with 10% Pt	0.15
Liu, 2014 (*Int. J. Hydrogen Energy*)	Graphite granules	Stainless steel mesh	0.15
Li, 2014 (*Sep. Purif. Technol.*)	Graphite granules	Polyester filter cloth, modified by in situ formed PANi (polyaniline)-phytic acid (PA)	0.78
This Study	**Carbon felt**	**C/TiO_2 ink cathode**	**1.02**

- **Can we provide an efficient treatment?**

The treated effluent generated in two-stage combined MFC-MBR process has the following characteristics:

Soluble COD: In the range of **30 – 40 mg/l**

BOD: Less than **5 mg/l**

TKN: **10 mg/l**

TSS: Less than **5 mg/l**

- **Can low-cost sustainable development of MFC-MBR technology be achieved?**

1. **Generation of high quality effluent – Membrane retains most particulate matter.**
2. **Combined process has smaller footprint for medium-scale organic wastewater treatment.**
3. **Easy operation and less space is required for reactor set-up**

Acknowledgement

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Thank You