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

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Gourav Dhar Bhowmick
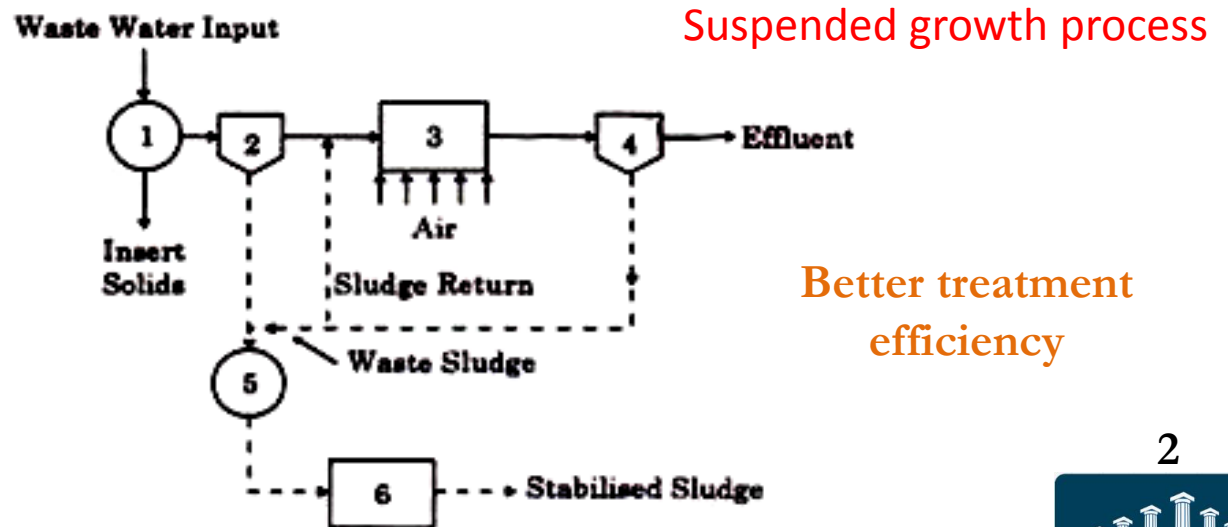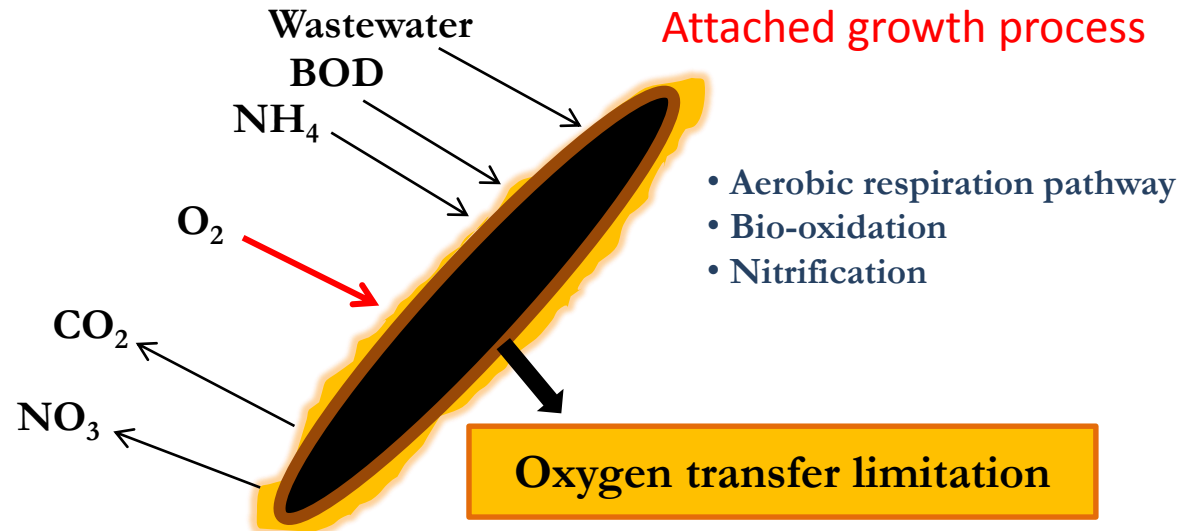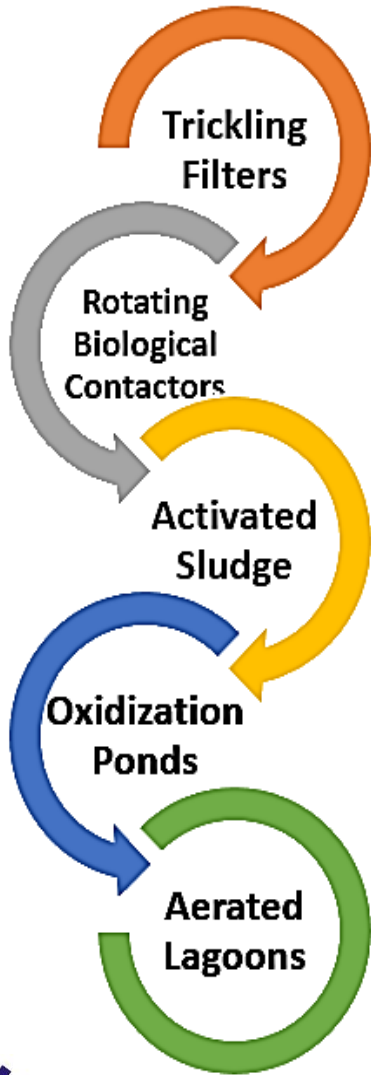**Prof. Makarand M. Ghangrekar**
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Commonly Used Aerobic Biological Wastewater Treatment Processes

Trickling Filters

Rotating Biological Contactors

Activated Sludge

Oxidization Ponds

Aerated Lagoons

Wastewater
BOD
NH_4

O_2

CO_2

NO_3

Attached growth process

- **Aerobic respiration pathway**
- **Bio-oxidation**
- **Nitrification**

Oxygen transfer limitation

Suspended growth process

Waste Water Input

1

2

3

4 → Effluent

Insert Solids

Air

Sludge Return

Waste Sludge

5

6 - - - → Stabilised Sludge

Better treatment efficiency

Membrane bioreactor (MBR) Technology

Biological – ASP   +   Membrane Filtration

First report

New York and Connecticut, US

Smith et al., 1969
Hardt et al., 1970

MBR installation for industrial wastewater treatment

Connecticut, US

Dorr-Oliver, Inc.

Submerged – MBR with flat-sheet UF plate & frame membrane (0.2-0.5 KWh/m³)

Japan

Yamamoto et al., 1989

Global MBR Market

$ 217 Million

$ 360 Million

$ 627 Million

Development of Integrated Processes
- AOP
- Reverse and forward osmosis
- Hybrid MBBR-MBR
- MBR – ozonation or UV/H_2O_2

| 1969 - 1970 | 1970 - 1980 | 1980-1990 | 2005 | 2010 | 2015 |

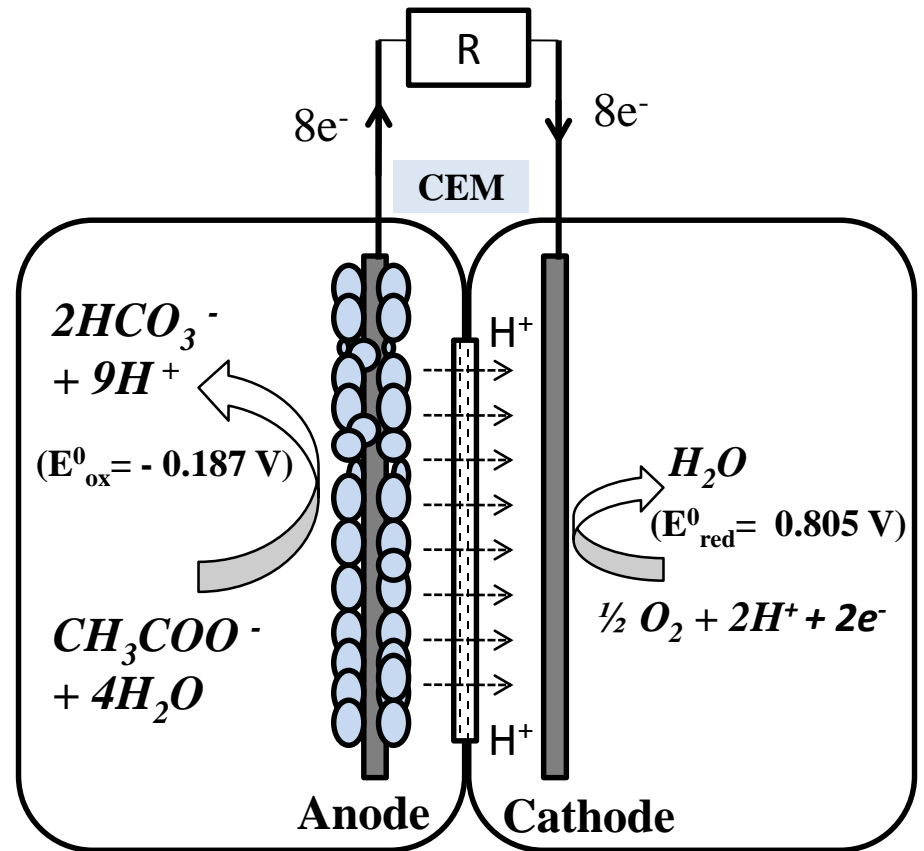# MBR technology involves high energy-consuming process

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?**

R

$8e^-$ $8e^-$

CEM

$2HCO_3^-$ $+ 9H^+$

H^+

$(E^0_{ox} = -0.187\ V)$

H_2O

$(E^0_{red} = 0.805\ V)$

CH_3COO^- $+ 4H_2O$

$½\ O_2 + 2H^+ + 2e^-$

H^+

Anode   **Cathode**

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.)

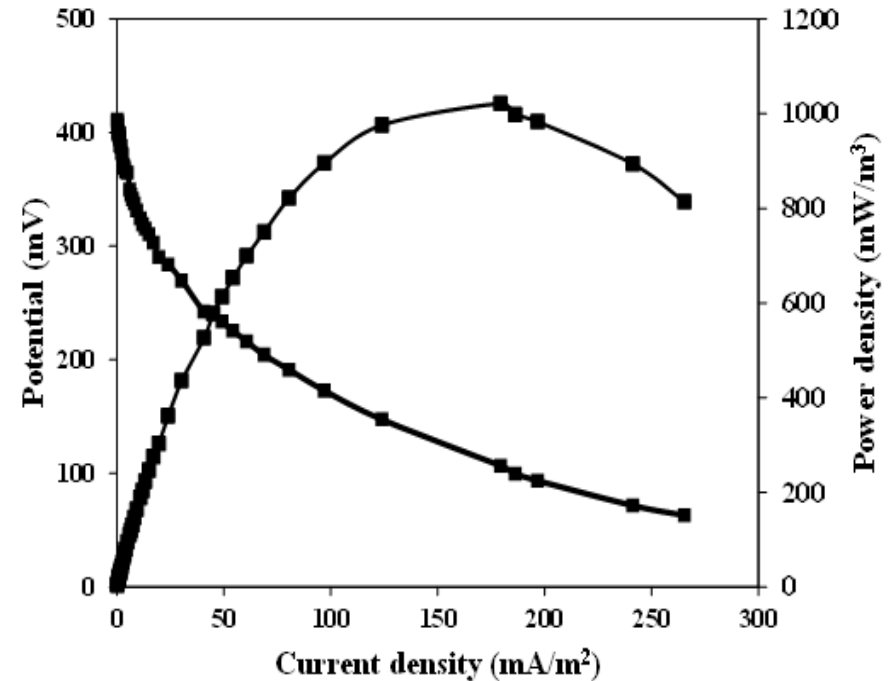**Total and soluble COD, MLSS, MLVSS, TKN and alkalinity** (APHA 1998)

6

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

7
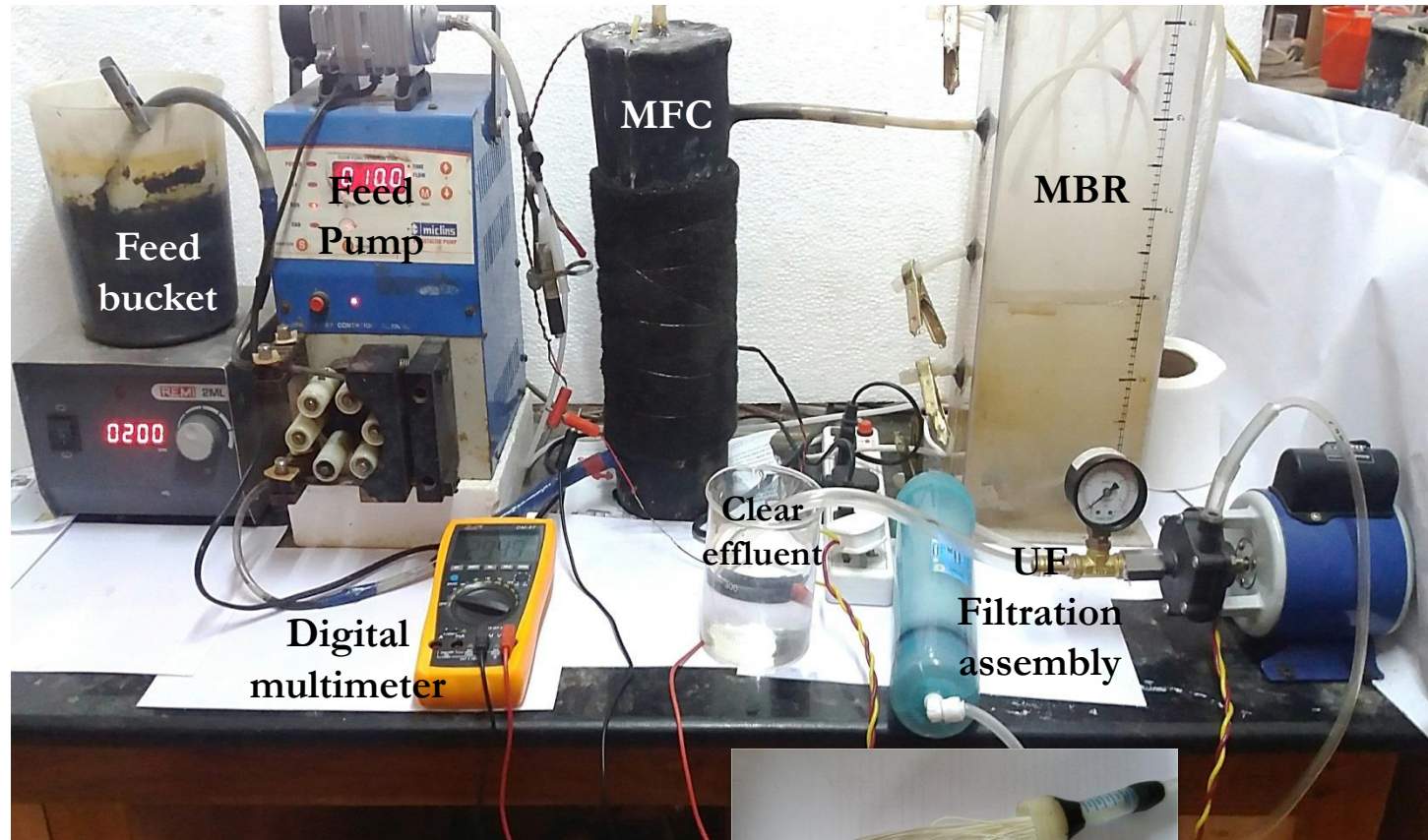
Generation of bio-electricity in MFC

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 %

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**.

Polarization and power curves for MFC

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
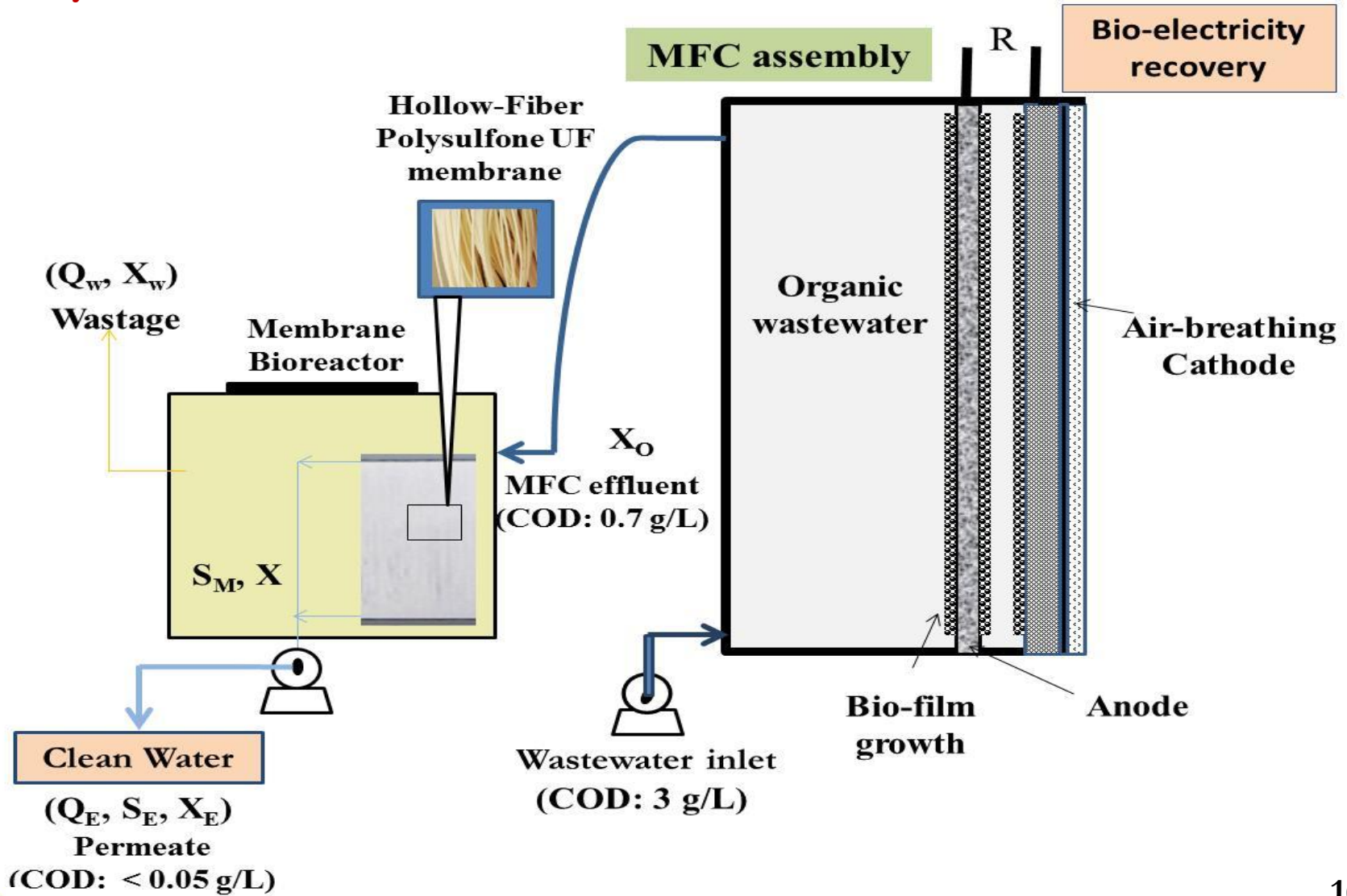NA= Not applicable: ND= Not detectable

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.

Kinetic Equations and Results

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

The rate of change of biomass in MBR: $\boldsymbol{V \cdot \dfrac{dX}{dt} = \mu XV - k_d \cdot XV - Q_w X - Q_E X_E}$

At steady state condition, $dX/dt = 0$: $\quad \boldsymbol{\mu = k_d + \dfrac{Q_w}{V} + \dfrac{Q_E}{V} \cdot \dfrac{X_E}{X}}$

$$\text{Sludge retention time,} \; SRT\,(\boldsymbol{\theta_c}) = \dfrac{VX}{Q_w X + Q_E X_E}$$

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

Thus, the final equation for substrate utilization: $\quad \boldsymbol{S = \dfrac{K_s\left(\frac{1}{SRT} + k_d\right)}{\mu_{m-}\left(k_d + \frac{1}{SRT}\right)}}$ The substrate balance

equation to demonstrate the expression for biomass generation in MBR:

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

- **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.**

- **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/1**
>
> BOD: Less than **5 mg/1**
>
> TKN: **10 mg/1**
>
> TSS: Less than **5 mg/1**

- **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

Thank You