FAPESP Week 2024
Illinois, USA April, 9th to 10th

Coffee session: Water
Classroom B

Membrane-based innovative approaches for **wastewater treatment and water reuse**

Prof. Eduardo Lucas Subtil, Ph.D.
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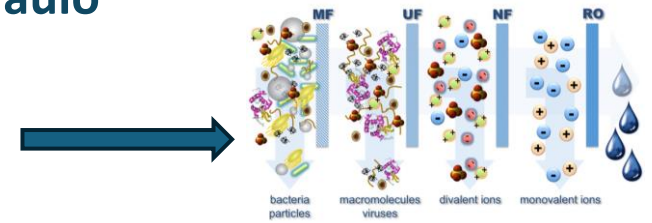
LabTAUS
Treatment Technologies for Urban Wastewater and Water Reuse

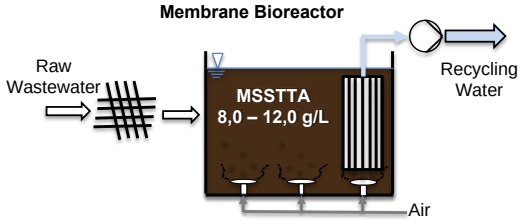
UFABC

❑ Membrane Processes for Urban Water Reuse in São Paulo

- **Membranes can remove** a wide range of contaminants, including suspended solids, bacteria, viruses, organic compounds and dissolved salts.



- **Modular, flexible design with a small footprint**



Aquapolo Project
ABC Region
Flow: 650 L/s (Equ Population of 500000 inhabitants)
Industrial reuse – Petrochemical industrial complex
Largest project for industrial water reuse in Latin America (fifth largest on the planet)

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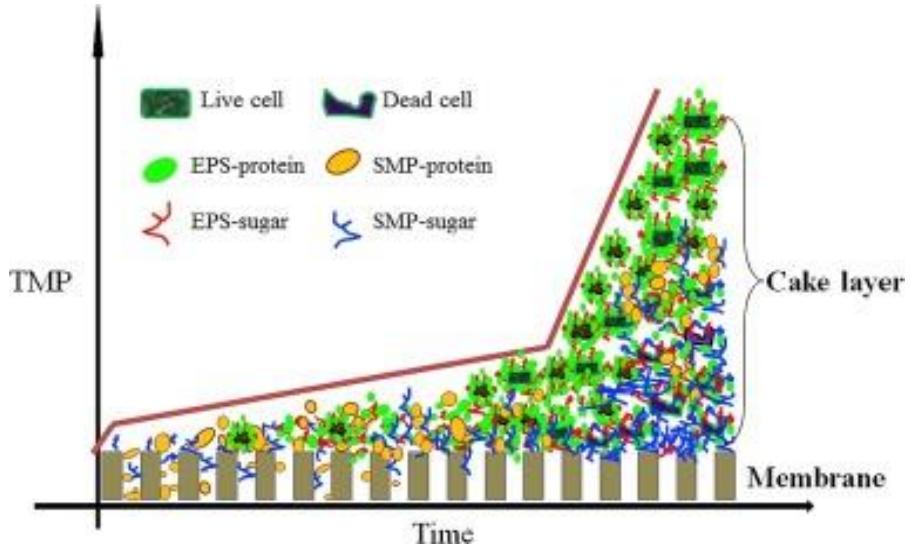
❑ Challenges

Fouling control

Energy consumption and GHG emissions

Fouling

Membrane fouling is a process by which different constituents are deposited or adsorbed onto the membrane pores or surface by physical and chemical interactions or mechanical action, which results in smaller or blocked membrane pores.



- Increase energy and chemical costs;
- Reduce the lifespam of the membrane;
- Increase capital costs.

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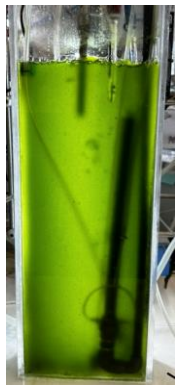
❑ Laboratory of Urban Wastewater Treatment and Water Reuse (LabTAUS)

Membrane bioreactors

- MBR (SND)
- AnMBR
- EMBR
- MPBR



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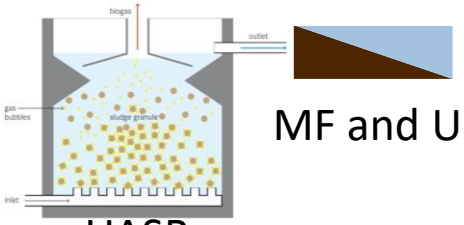
Antifouling membranes

Polyaniline (PANI)

Graphene Oxide
Zinc oxide

Post-treatment of anaerobic effluent (UASB) by UF membranes



UASB

MF and UF

Fouling control through coagulation/flocculation using natural-based coagulants.

International Collaborations

Next?

UNSW SYDNEY

Centre for Membrane Science and Technology

UAM Universidad Autónoma de Madrid

UPC UNIVERSITAT POLITÈCNICA DE CATALUNYA BARCELONATECH

❑ Simultaneous Nitrification and Denitrification - MBR

Journal of Water Process Engineering 32 (2019) 100995

Contents lists available at ScienceDirect

Journal of Water Process Engineering

journal homepage: www.elsevier.com/locate/jwpe

Pilot-scale investigation on the feasibility of simultaneous nitrification and denitrification (SND) in a continuous flow single-stage membrane bioreactor

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ARTICLE INFO

Keywords:
Nitrogen removal
Dissolved oxygen
Extracellular polymeric substances
Fouling

ABSTRACT

The aim was to evaluate the effect of three different dissolved oxygen concentration (DO) on membrane fouling and foulants production as well as in the removal of nitrogen and organic matter by Simultaneous Nitrification and Denatrification (SND). For this purpose, a sMBR pilot plant was operated with continuous flow and no separated anoxic zone. Experiments were carried out in three phases, i.e. phase I, II and III, with DO 2.0, 0.8 and 0.4 mg/L, respectively. Under these conditions, a good performance in terms of COD and $BOD_{5,20}$ was obtained, removals higher than 96% and 97%, respectively. The nitrification was almost complete, even when the dissolved oxygen concentration was the lowest, Phase III. The reduction of DO concentration positively impacted the total nitrogen removal through SND, especially in Phase II, resulting in an average total nitrogen removal of 66%, while in Phase I, the average removal was only 28%. Sludge filterability, membrane performance and total resistance of mixed liquor under SND conditions when the DO was 0.8 ± 0.1 mgO_2/L were not significantly affected. Conversely, a significant change was observed when the DO concentration was reduced to 0.4 mg ± 0.1 mg O_2/L.

ENVIRONMENTAL TECHNOLOGY
https://doi.org/10.1080/09593330.2021.1950843

Taylor & Francis
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Simultaneous nitrification-denitrification (SND) using a thermoplastic gel as support: pollutants removal and microbial community in a pilot-scale biofilm membrane bioreactor

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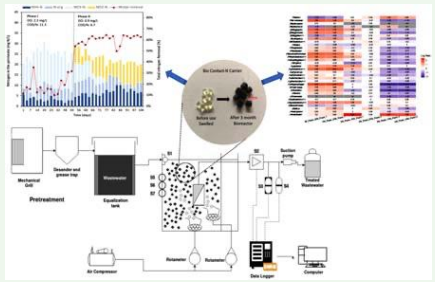
ABSTRACT

In this study, experiments were carried out to treat sanitary wastewater in a biofilm membrane bioreactor using a thermoplastic gel as a support to assist the nitrification-denitrification process. For this purpose, the system was operated in two different dissolved oxygen concentrations (2.3 ± 0.2 and 0.9 ± 0.3 mg O_2/L for Phases I and II, respectively) and the removal of organic compounds and nitrogen, as well as the microbial community in suspended biomass and biofilm were evaluated. The MB-MBR system was able to withstand raw wastewater variations and maintaining a low permeate COD concentration (18 mg/L) even at low DO concentrations. On the other hand, it was found that oxygen concentration significantly influenced the process of nitrogen conversion. In Phase I the average removal of total nitrogen was 18 ± 8%, while in Phase II it increased to 66 ± 11%. The denitrification rate was two times higher (7.8 mg NO_3^-–N/h) at low dissolved oxygen, with a significant contribution of the biofilm (41%). Additionally, the high-throughput 16S rDNA sequencing showed that the oxygen concentration was determinant for arrangement patterns of the samples and not the sampling site (suspended biomass and support material). *Thiothrix*, *Comamonas*, *Rhodobacter*, *Mycobacterium*, *Thermomonas*, *Sphingobium*, *Sphigopyxis*, *Pseudoxanthomonas*, *Nitrospira* and, *Novosphingobium* were the main genera regarding the nitrogen cycle.



ARTICLE HISTORY
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Accepted 23 June 2021

KEYWORDS
Biofilm carriers; sanitary wastewater treatment; simultaneous nitrification and denitrification; 16S rDNA sequencing

❑ Antifouling membrane

Chemical Engineering Journal 441 (2022) 136004

Contents lists available at ScienceDirect

Chemical Engineering Journal

journal homepage: www.elsevier.com/locate/cej

Direct membrane filtration (DMF) of municipal wastewater by mixed matrix membranes (MMMs) filled with graphene oxide (GO): Towards a circular sanitation model

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ARTICLE INFO

Keywords:
Resource recovery
Ultrafiltration
Foulants
Methane
Water reuse
Nanomaterials
Graphene oxide

ABSTRACT

Direct membrane filtration (DMF) is an emerging wastewater treatment technology for providing high-quality effluents as well as efficient organic waste recovery from the concentrate. The latter may then be used for methane production, a renewable energy source. However, widespread application of DMF in large systems still faces challenges due to fouling effects. In this work, polyethersulfone-graphene oxide (PES-GO) ultrafiltration membranes were successfully synthesized by phase-inversion and applied for the first time in a DMF system for a real municipal wastewater. The incorporation of GO resulted in membranes showing increased flux recovery, higher rejection capacity and enhanced irreversible fouling resistance which could be mainly attributed to their more hydrophilic and restrictive selective layer. More specifically, PES-GO(0.6%) membrane reached 91% of flux recovery, indicating a substantial improvement in the membrane reusability when compared to PES membrane. The findings of cake layer characterization confirm that changes in the membrane surface caused by the addition of GO allowed for a reduction in protein deposition, and that its contribution to fouling formation during DMF is greater than carbohydrates. Thereby, these results show promising features for GO modified membranes in DMF systems aiming organic matter recovery for self-energy sustainable wastewater treatment plants.

Contents lists available at ScienceDirect

Chemical Engineering Journal

journal homepage: http://ees.elsevier.com

Preparation and characterization of a new composite conductive polyethersulfone membrane using polyaniline (PANI) and reduced graphene oxide (rGO)

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ARTICLE INFO

Keywords
Membrane separation process
Nanomaterials
Phase-inversion
Fouling

ABSTRACT

A new polyethersulfone (PES) composite membrane using nanostructures of polyaniline (PANI) and reduced graphene oxide (rGO) was prepared by the phase inversion process. The investigation focused on the use of PANI and rGO as conductive dopants, along with camphorsulfonic acid (HCSA) and dodecylbenzene sulfonic acid (DBSA) for PANI preparation. Higher conductivity was obtained for the membrane doped with PANI-DBSA (4.5 ± 0.3 μS·cm ^{1}). The membrane conductivity was further increased to 9.6 ± 0.8 S·cm ^{1}, 10 times higher than the conductivity of the PES-control membrane, by incorporating rGO (PES-PANI(DBSA)-rGO(0.2 g). The use of HCSA as PANI dopant resulted in membranes with higher hydrophilicity compared to the ones obtained with the PANI-DBSA. The contact angle reduced from $61.9 \pm 2.0°$ (PES-control) to $45.2 \pm 1.5°$ for PES-PANI(HCSA)-rGO(0.2 g). Moreover, the incorporation of rGO also resulted in fewer but larger macrovoids in the membranes bottom layer and a roughness (R_a) reduction. More specifically, for PES-PANI(HCSA)-rGO(0.2 g), R_a dropped to 2.7 ± 0.4 nm when compared to PES membrane control (11.6 ± 3.4 nm). PANI addition significantly improved membrane permeability, which was further increased with the addition of rGO. Fouling studies revealed that the PES-PANI(HCSA)-rGO(0.2 g) membrane featured higher flux recovery ratio (FRR) ($81.3 \pm 3.6\%$) than PES-PANI(DBSA)-rGO(0.2 g) ($60.9 \pm 5.8\%$) and PES-control membrane ($21.8 \pm 5.7\%$). After electrochemical cleaning, an additional increase of the flux recovery ratio (FRR) was obtained for conductive membranes. In summary, the composite membranes, specially the HCSA-doped membrane, presented improved operating performance and fouling mitigation.

ACCEPTED PROOF

❑ Post-treatment of UASB reactor by coagulation assisted UF membrane

Journal of Environmental Chemical Engineering 8 (2020) 104066

Contents lists available at ScienceDirect

Journal of Environmental Chemical Engineering

journal homepage: www.elsevier.com/locate/jece

Pre-coagulation assisted ultrafiltration membrane process for anaerobic effluent

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ARTICLE INFO

Editor: GL Dotto

Keywords:
Wastewater treatment
Fouling mitigation
Coagulant
Flocculation
Foulants

ABSTRACT

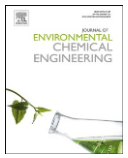
Membranes can be used as alternative for post-treatment of upflow anaerobic sludge blanket (UASB) reactors. However, mainly for anaerobic effluent, fouling is still a challenge and major drawback can be minimized by coagulant addition before membrane filtration. In this work, three concentrations of aluminum sulfate (20, 150, and 950 mg L^{-1}) were applied in UASB effluent to evaluate pollutant removal and fouling mitigation potential in two steps: coagulation/flocculation and crossflow filtration with ultrafiltration membrane. All coagulant dosages removed foulants (e.g. carbohydrates and proteins) before filtration and supernatants showed lower flux decrease in relation to UASB effluent, with an enhancement in reversible fouling fraction in comparison with total fouling resistance. Scanning Electron Microscopy and Energy Dispersive X-Ray Spectroscopy (SEM-EDX) analyses showed efficient coagulation and precipitation resulting in less residual aluminum in membrane surface for 950 mg L^{-1} coagulant dosage. All coagulants concentrations altered the cake layer, assisting crossflow filtration. Coagulation of UASB effluent before membrane filtration indicate an interesting alternative for post-treatment of anaerobic effluent.

Journal of Environmental Chemical Engineering 11 (2023) 109778

Contents lists available at ScienceDirect

Journal of Environmental Chemical Engineering

journal homepage: www.elsevier.com/locate/jece



Assessment of natural tannin-based coagulant for effective ultrafiltration (UF) of UASB effluent: Fouling mechanisms, pollutant removal and water reclamation feasibility

Rodrigo Almeria Ragio [a], Camila Clementina Arantes [a], Joan García [b], Eduardo Lucas Subtil [a,*]

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ARTICLE INFO

Editor: Ana Loncaric Bozic

Keywords:
Wastewater treatment
Membrane filtration
Coagulation
Organic coagulant

ABSTRACT

In this work, tannin coagulant (TANm) was applied at different dosages and compared with a PACl for UASB effluent filterability enhancement during membrane ultrafiltration. The results showed that TANm exhibited the greatest potential to improve UASB effluent filterability. Flux decay, total fouling resistance, and specific cake layer resistance were all reduced by both coagulants. However, the highest flux (55%) and fouling resistance reduction (70%) were obtained with 40 mg.L^{-1} of TANm, which was caused by an increase in particles larger than 200 μm, facilitating its removal by cross-flow filtration. Protein and carbohydrate reduction in the membrane was only observed at 25 mg.L^{-1} for both coagulants, with a higher influence of proteins in strongly/very strongly bound for all samples. In addition, fouling irreversibility increases, with a strong correlation between TANm dosage and R_{irr} and complete and intermediate pore blocking pointed as the main mechanisms responsible for irreversibility for both coagulants. Based on these and other findings, the mechanisms of the fouling layer adhered to the membrane with coagulants included the formation of complexes with proteins that were more strongly adhered (related to UASB effluent zeta potential increase), the density of the cake layer due to the presence of compact aggregates, and action of the coagulants themselves as foulants. Lastly, the economic evaluation revealed that the system without coagulant would have a lower total cost, but payback showed that the application of TANm has a lower investment time of return due to a lesser CAPEX.

❑ Novel concept for wastewater treatment and water reuse

Ongoing project

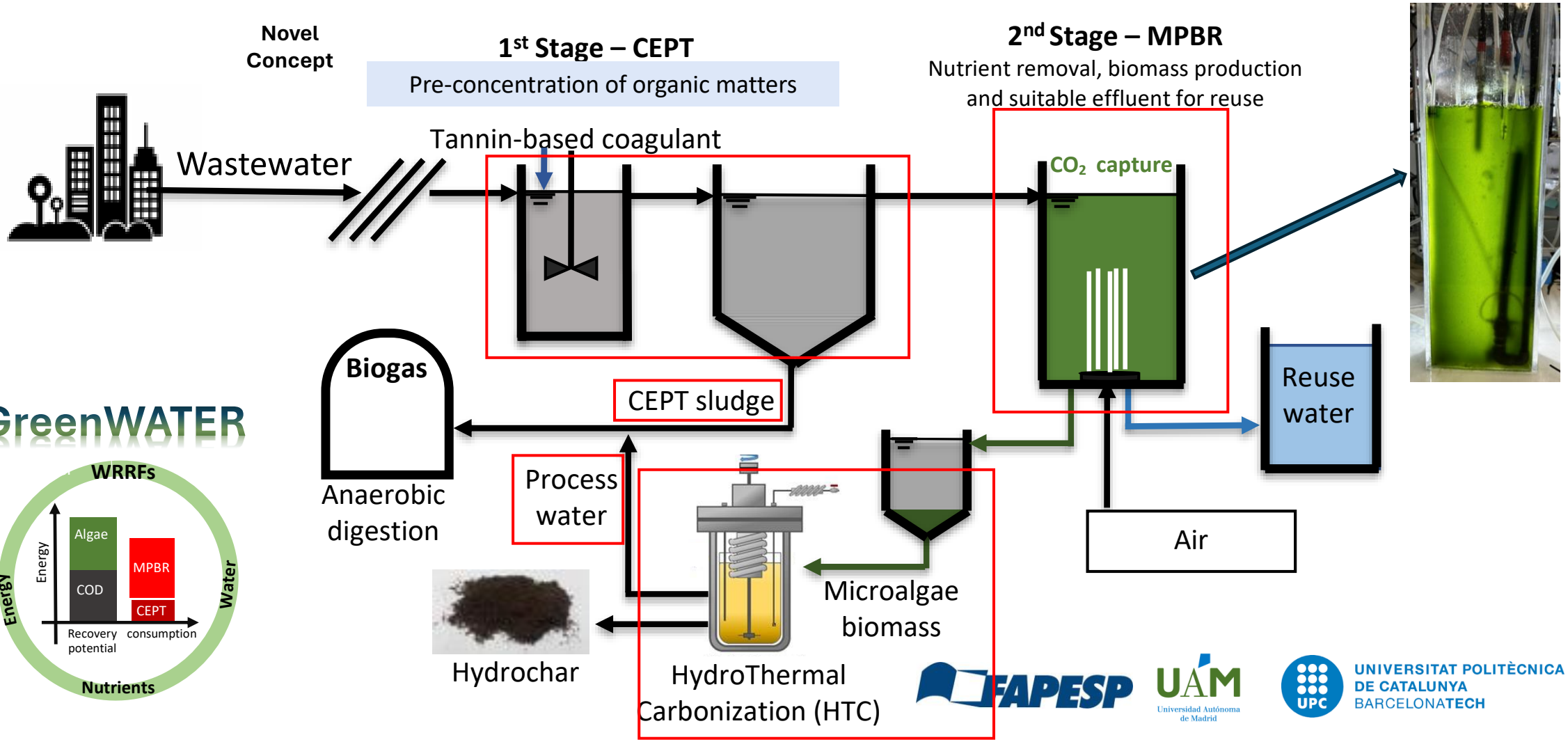
Novel Concept

1st Stage – CEPT

Pre-concentration of organic matters

2nd Stage – MPBR

Nutrient removal, biomass production and suitable effluent for reuse



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LabTAUS Treatment Technologies for Urban Wastewater and Water Reuse

UFABC

Thanks!

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Questions to the audience:

- ❑ Can we identify any common challenge, some potential research topics, or areas where collaboration could lead to innovative solutions in water-related issues?

- ❑ Are there any successful case studies from other researchers that could inspire collaborative efforts between Brazil and the US?