Towards resource recovery from industrial wastewater treatment by tubing two-phase partitioning bioreactors: challenges and perspectives

***M.C. Tomei*, D. Mosca Angelucci**
Water Research Institute – CNR- Rome, Italy

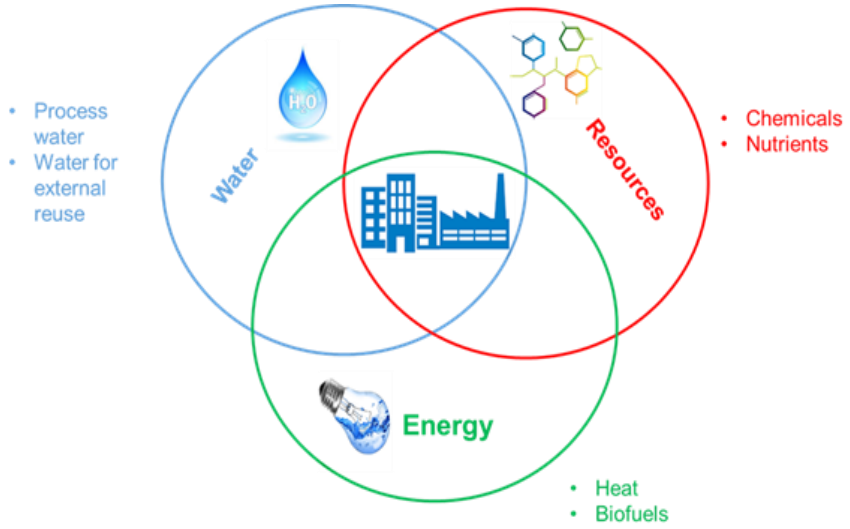
GUAYAQUIL, 30 SEPTEMBER – 3 OCTOBER 2019

OUTLINE

- **Introduction:** *biological treatment of industrial wastewater and resource recovery*
- **Objectives**
- **Technology: Solid-liquid Two-phase Partitioning Bioreactors (TPPBs)**
  - *Granular-Polymer TPPBs*
  - *Tubing TPBBs*
- **Experimental**
- **Results and discussion**
- **Conclusions and future developments**

INTRODUCTION

Energy and resource recovery concept in industry



Challenge of biological treatment for recovery

Effluent composition :

- diverse types of pollutants including additives, solvents, biocides, and other **toxic organic compounds** potentially biodegradable but often difficult to biodegrade (usually at high concentrations)
- **inorganic components (i.e. tanning agents, heavy metals, salts)**, which would normally be incompatible for biological treatment causing a ***"hostile" reaction environment***

OBJECTIVES

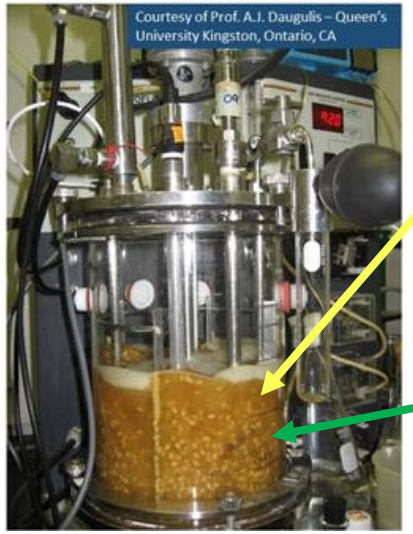
To demonstrate the feasibility of the tubing-TPPB system for treating industrial wastewater

Effective removal of the organic load

Complete separation for recovery (when suitable) of inorganics

TPPBS: TWO-PHASE PARTITIONING BIOREACTORS

Solid-liquid TPPB: principle of operation



Granular polymer acts as partitioning phase

Aqueous phase with the biomass

- ✓ Addition of polymer beads to a conventional bioreactor
- ✓ Substrate partitions between polymer and liquid phase
- ✓ Release of substrates into liquid phase, where biodegradation occurs

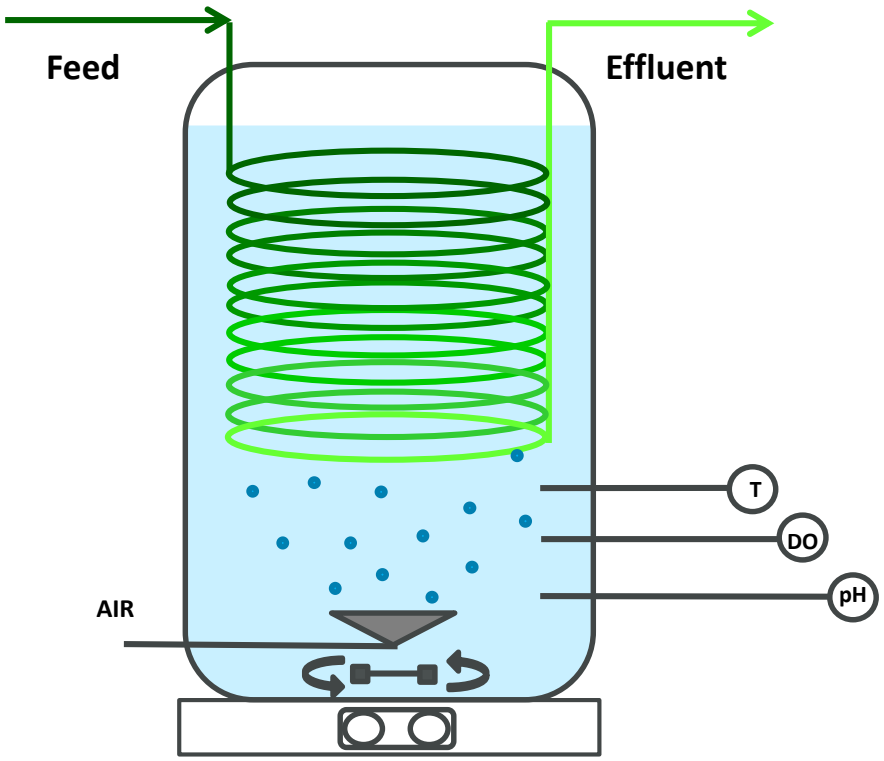
Features

- Self-regulating system (based on metabolic processes)
- Effective in presence of high xenobiotic concentration for biomass inhibition control
- Application to industrial wastewater treatment (more advantageous in sequential systems)

TUBING-TPPB

Tubing-TPPB: principle of operation

Configuration of an Extractive Membrane Bioreactor (Livingston et al., 1998) operated with polymeric (instead of silicon rubber) tubing suitable for a wider spectrum of organics



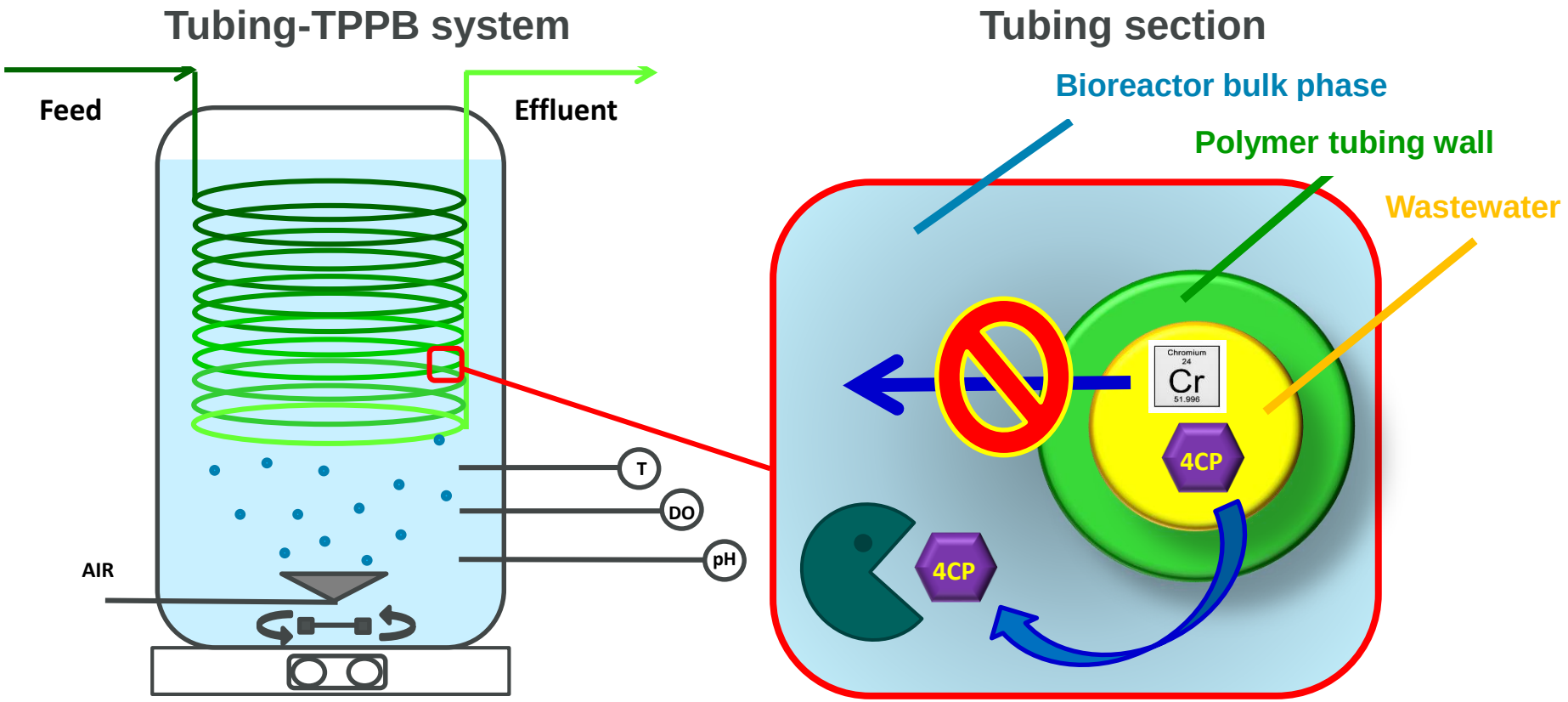
- A coiled polymeric tubing is immersed in the bioreactor
- Wastewater flows inside tubing
- Organic substrate diffuses across tubing walls towards bioreactor liquid side
- Biodegradation occurs in the bulk phase containing the biomass

Livingston A.G. et al. (1998) J. Membr. Sci. 151, 29-44.

TUBING-TPPB

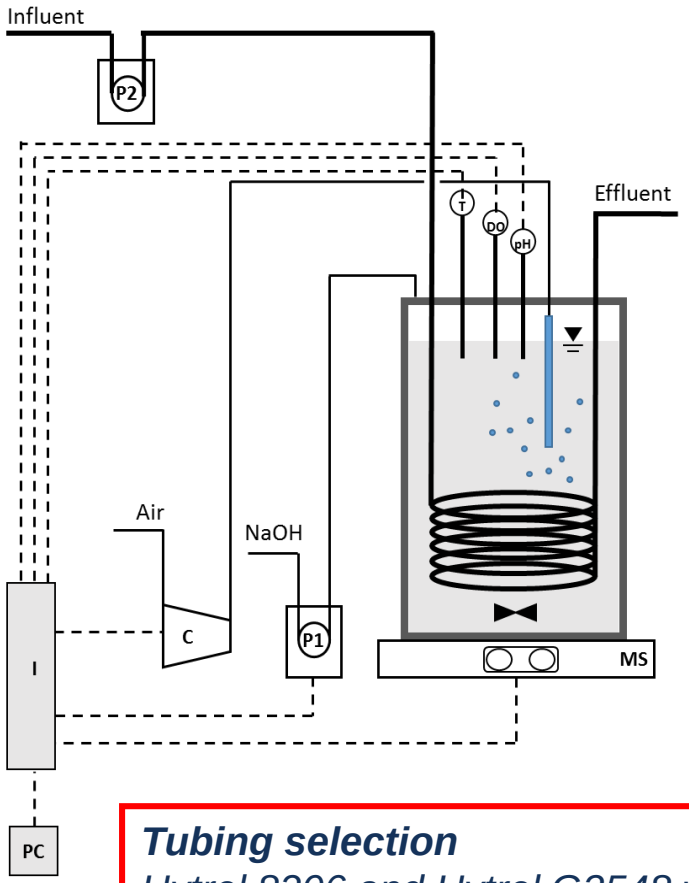
Features

- Selective transfer and **removal** of organics and **simultaneous separation for recovery** of inorganics
- **Separation of the biomass from the wastewater** is advantageous for the application to «hostile» industrial wastewater
- **Continuous operation (C-TPPB)**



EXPERIMENTAL

Tubing made of Hytrel (DuPont, Canada)		
Lenght	3.5-5.5	m
Internal volume	0.1	L
Internal flow rate	0.02-0.06	L/h
Tubing-TPPB bioreactor		
Volume	4	L
Temperature	27	°C
pH	7.5	-
Dissolved Oxygen (DO)	3-4	mg/L
Tannery wastewater (TW)		
4-chlorophenol (4CP)	1-2.5	g/L
Potassium Dichromate (as CrVI)	100	mg/L
Saline wastewater (SW)		
2,4-dimethylphenol (DMP)	1.2	g/L
Sodium Chloride (NaCl)	100	g/L



Tubing selection

Hytrel 8206 and Hytrel G3548 were selected for tannery and saline wastewatwer respectively, according to previous results on the use of this material in granular form.

Tomei et al., J. Environ. Manag. (2015) 150, 81–91;
Tomei et al., Sci.Tot. Env. (2017), 500-600, 1056-1063.

EXPERIMENTAL

- **Abiotic tests**
  Mass transfer tests (continuous feed for 24 h)

- **Biotic tests**
  Biodegradation tests (***continuos feed with increasig step loading conditions***) by using a mixed culture already acclimatized to 4CP/DMP to inoculate the tubing-TPPB system

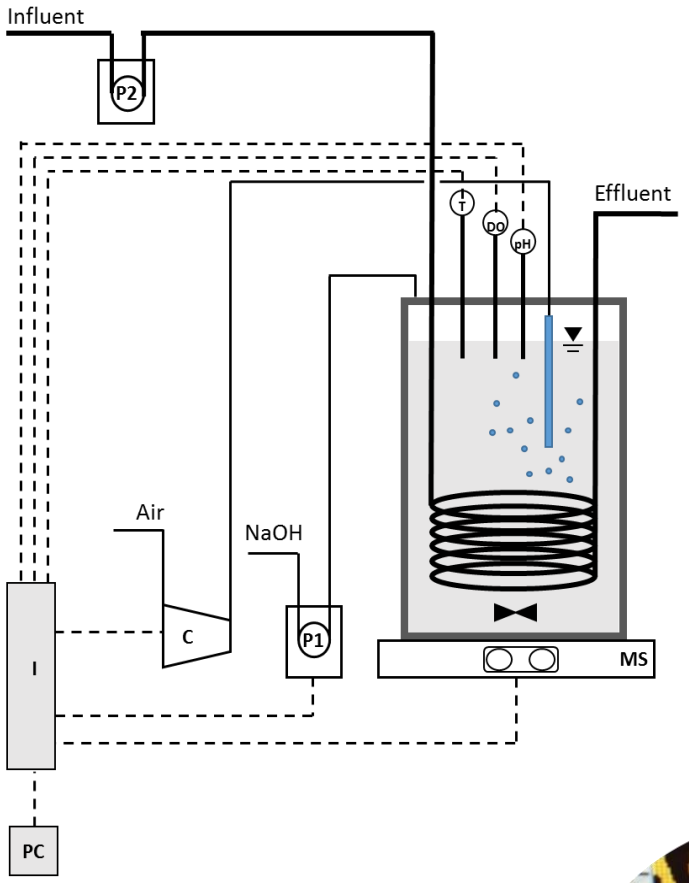
Analysis of 4CP and CrVI (TW)
Analysis of DMP andl Cl^- (SW)

- Bioreactor
- Tubing effluent
- Collected effluent

To evaluate mass balance

On-off control of DO, i.e. on line evaluation of the Specific Oxygen Uptake Rate (SOUR)

To evaluate metabolic activity

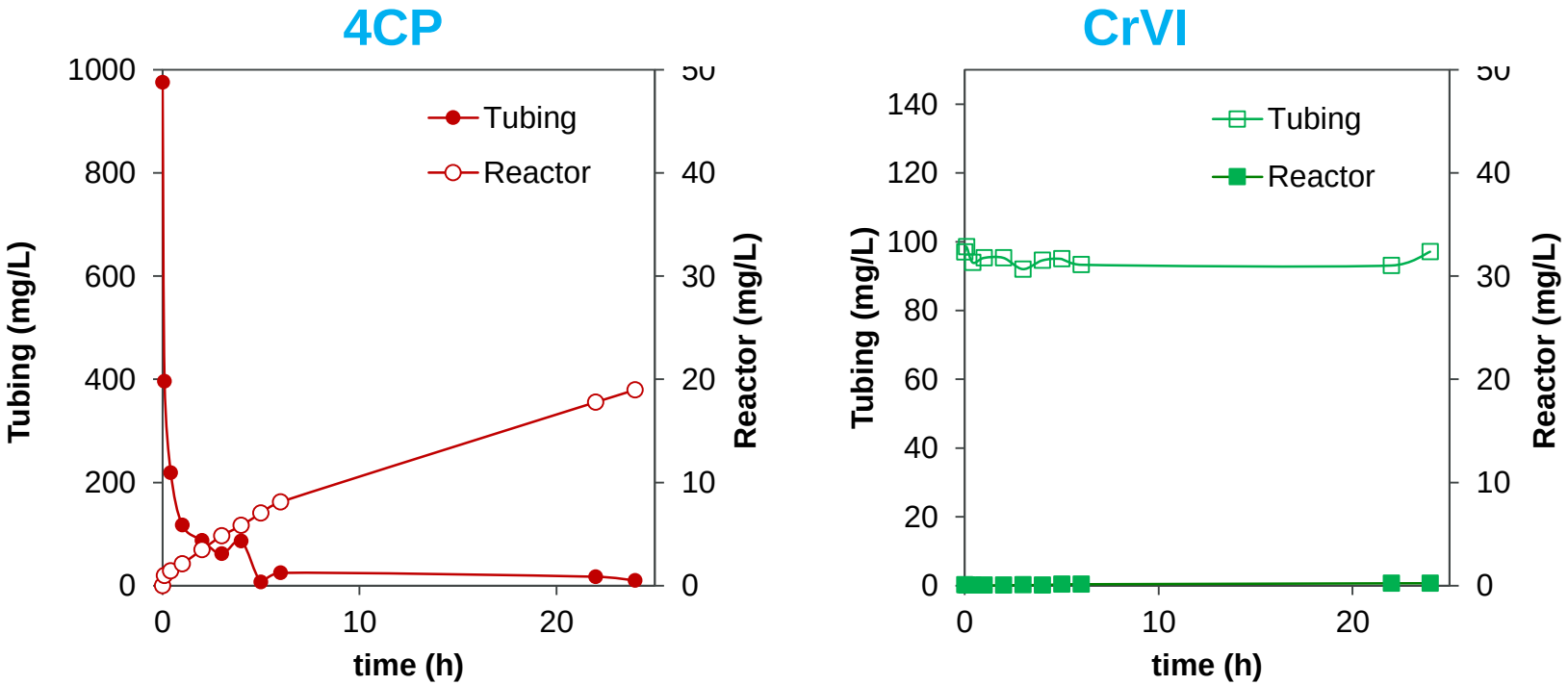


RESULTS AND DISCUSSION - TANNERY

Abiotic test for mass transfer study

Hytrel 8260

MT_TW Influent : 4CP = **1000** mg/L
CrVI = **100** mg/L

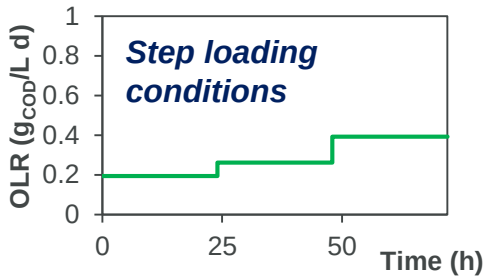


Removal of 4CP from wastewater 97% after 6 h

No transfer of CrVI through the polymer tubing

RESULTS AND DISCUSSION - TANNERY

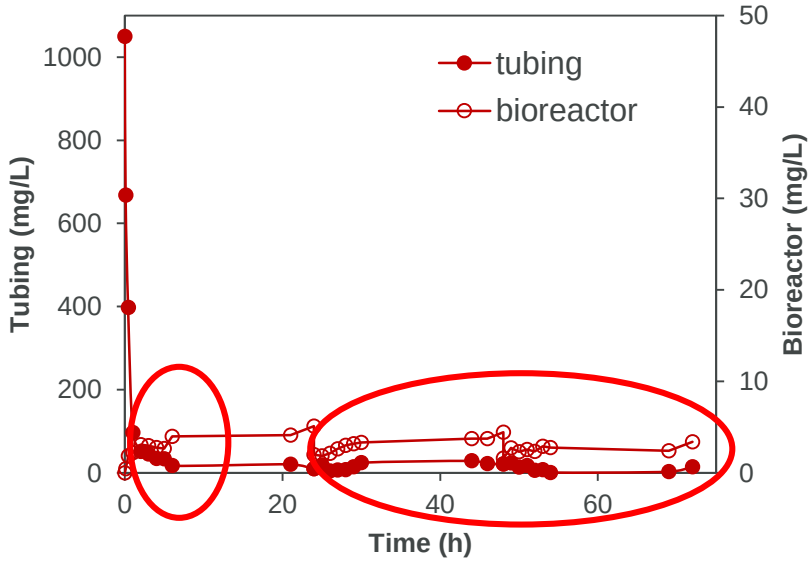
Biotic test – Concentration profiles



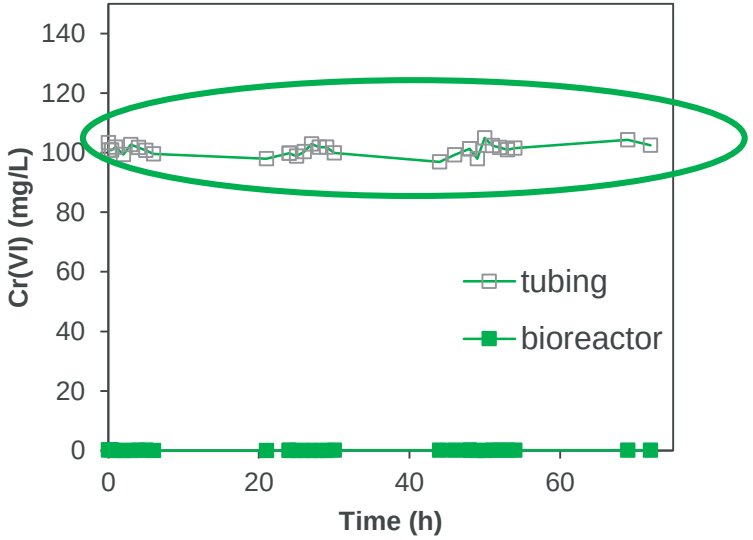
BIO_TW2

Influent : 4CP = **1000** mg/L
CrVI = **100** mg/L
Biomass: X = **0.98** g_{VSS}/L

4CP



CrVI



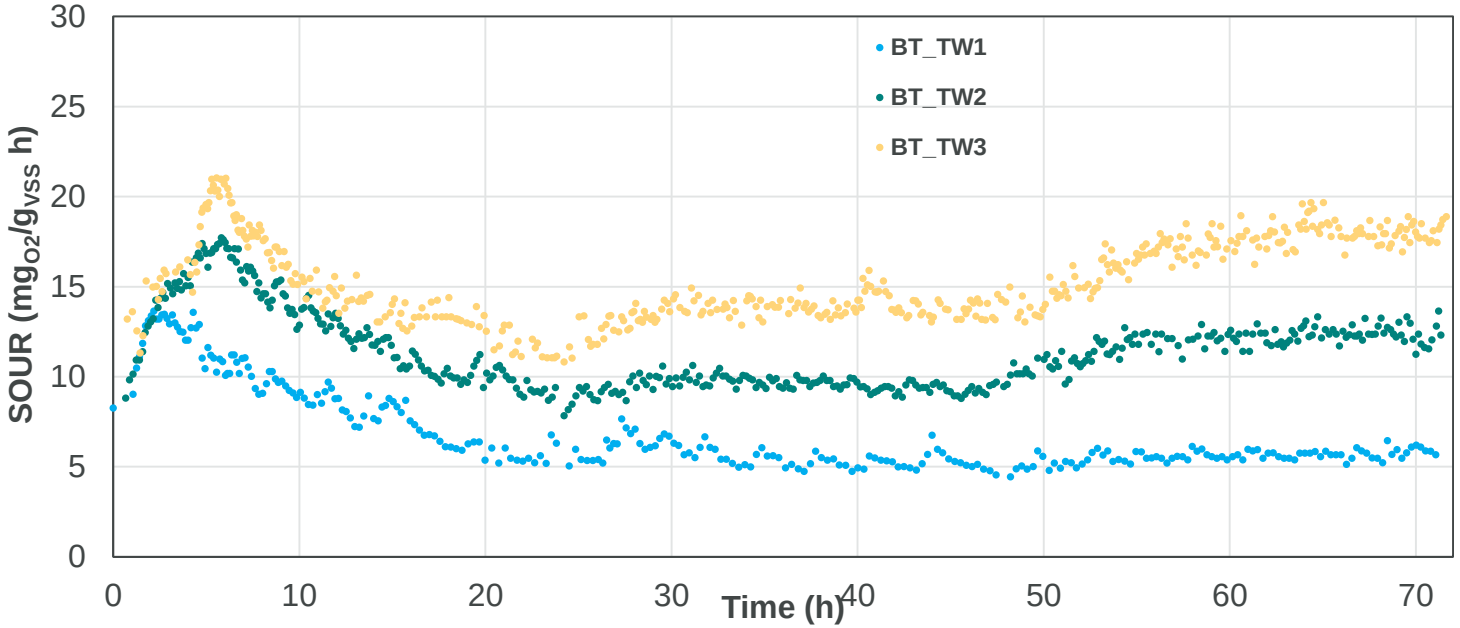
Removal of 4CP from wastewater 98% after 5 h and 99% from 24 to 72 h

Complete recovery of CrVI in the tubing effluent

RESULTS AND DISCUSSION - TANNERY

Biotic test – SOUR

	BIO_TW1	BIO_TW2	BIO_TW3
4CP (mg/L)	1000	1500	2500
CrVI (mg/L)	100	100	100
OLR (g_{COD}/L d)	0.19-0.39	0.27-0.59	0.46-0.95
Biomass (g_{VSS}/L)	0.98	1.02	1.24



In spite of the increased influent concentration, it was observed no inhibition and enhanced microbial activity

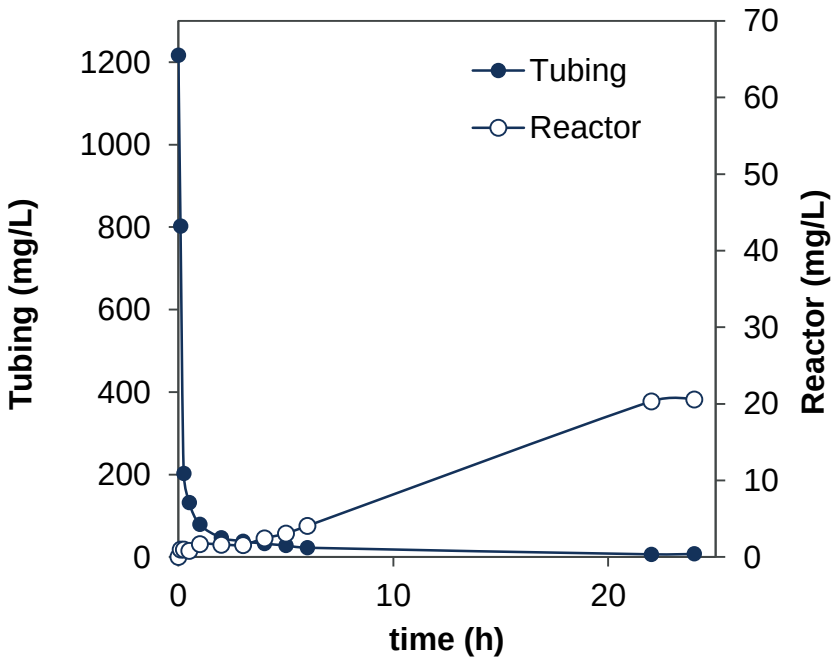
RESULTS AND DISCUSSION - SALINE

Abiotic test for mass transfer study

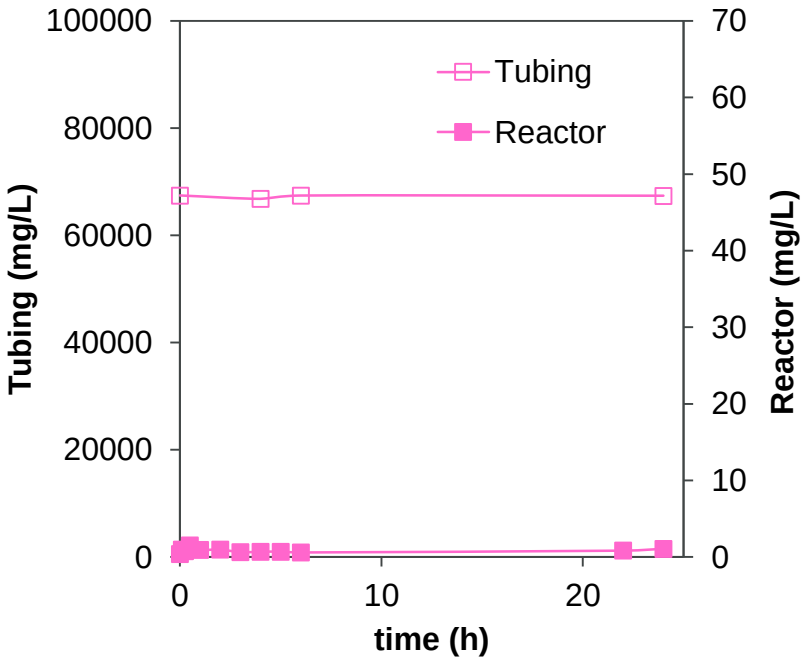
Hytrel G3548

MT_SW Influent : DMP = **1200** mg/L
NaCl = **100** g/L

DMP



Cl^-

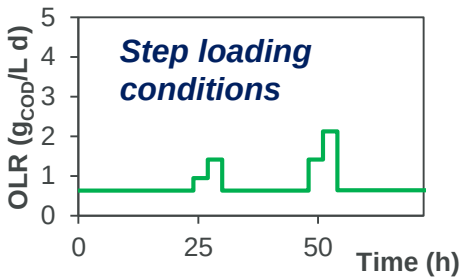


Removal of DMP from wastewater 98% after 6 h

No transfer of NaCl through the polymer tubing

RESULTS AND DISCUSSION - SALINE

Biotic test – Concentration profiles



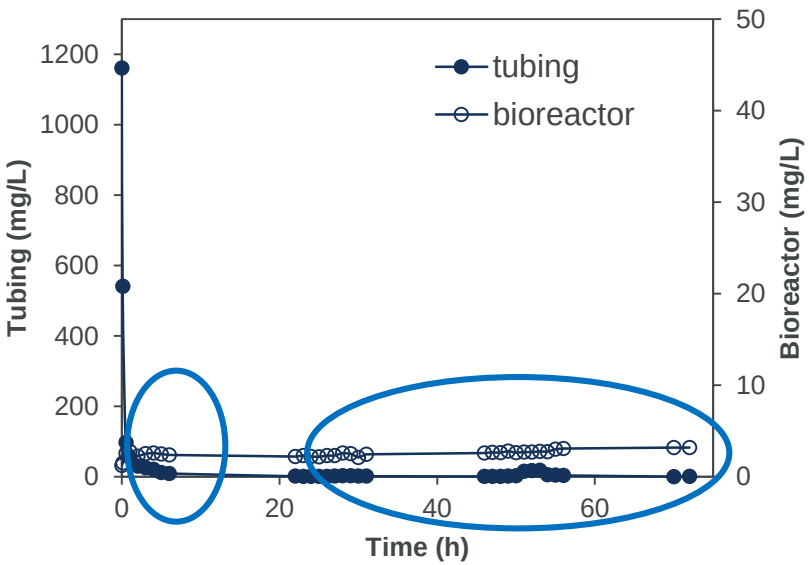
BIO_SW

Influent : DMP = **1200** mg/L

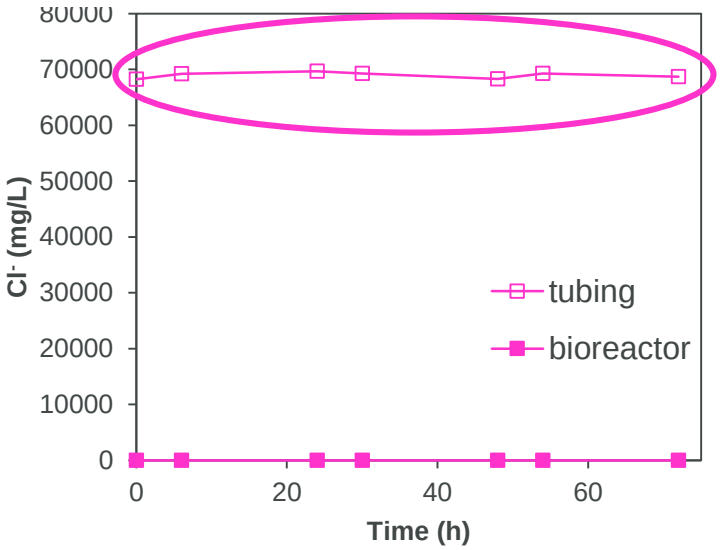
Cl^- = **100** g/L

Biomass: X = **1.37** g_{VSS}/L

DMP



Cl^-



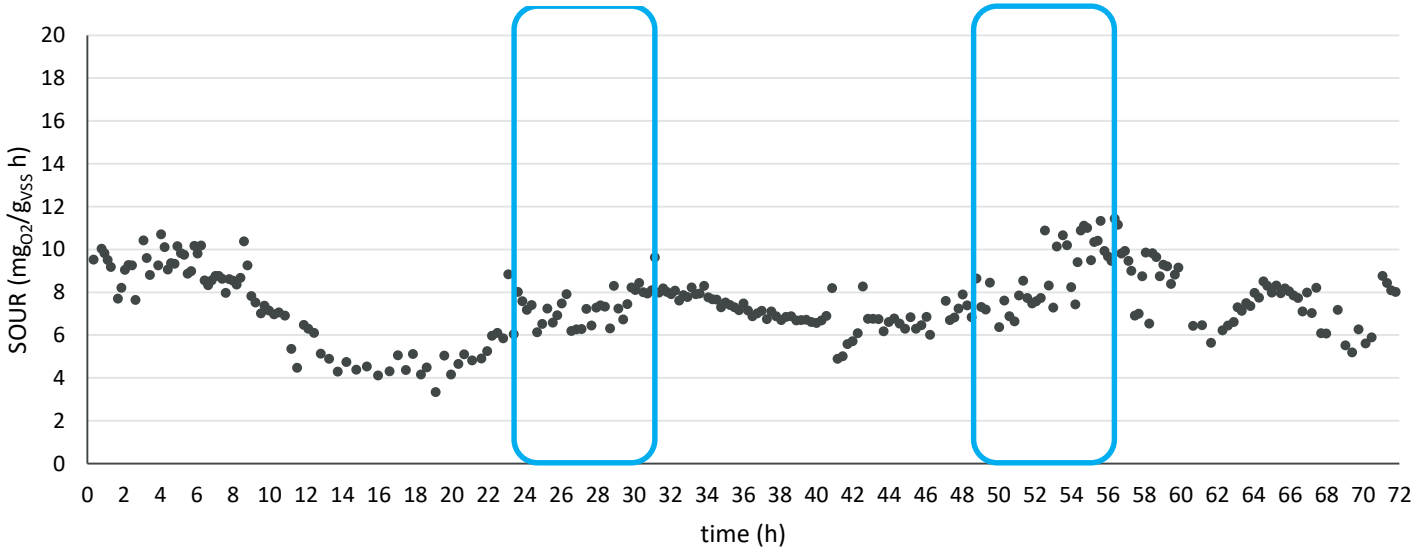
Removal of DMP from wastewater 99% after 5 h and until 72 h

Complete recovery of NaCl in the tubing effluent

RESULTS AND DISCUSSION - SALINE

Biotic test – SOUR

Step increasing loads

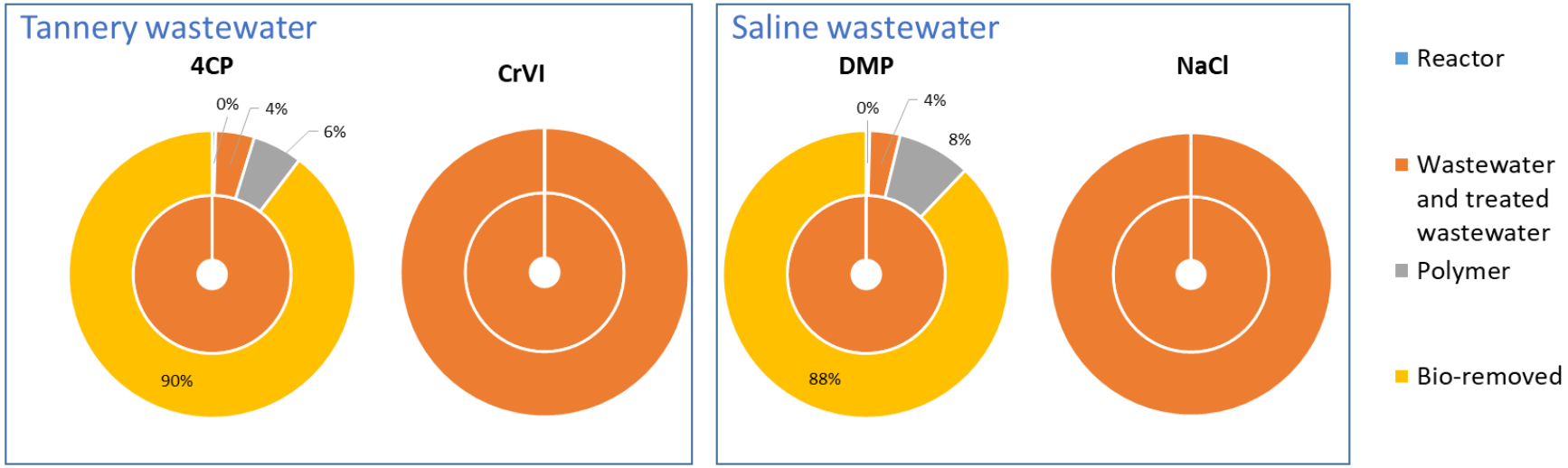


In spite of the increased influent flow rate, it was observed no inhibition and enhanced microbial activity

RESULTS AND DISCUSSION

Biotic test – Mass balance

Overview of distribution of investigated compounds during BT tests.
(Inner circle is for t=0 and outer circle is for t=72 h)



- Biodegradation efficiencies were within the range of 88-90%
- The fraction retained by the polymer itself has been always <9% of the fed amount, so demonstrating that the effective degradation of the organics transferred across the polymer walls and not only the sorption took place

CONCLUSIONS

- The proposed hybrid bioreactor has significant potential in treating “hostile” industrial wastewater
- Biodegradation of toxic organic molecules was successfully achieved and the microbial activity was not affected by the influent wastewater composition and concentration
- The hybrid bioreactor achieved the complete recoverable inorganic separation
- The high quality level of the effluent would allow the water reuse in the production cycle and/or the recovery of valuable resources

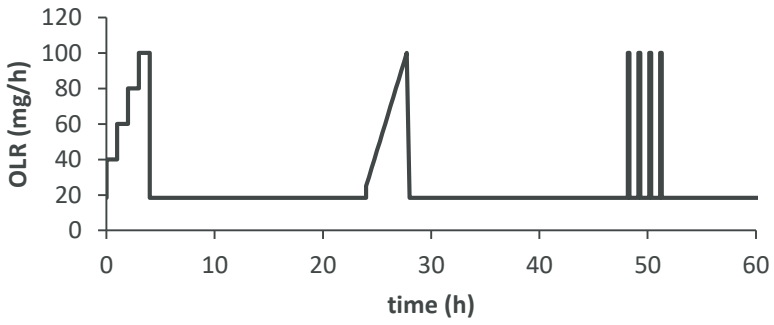
The demonstrated advantages of tubing-TPPB system fall within the basic principles of “*reduce, reuse and recycle*” required by a cleaner and eco-efficient improved production.

ONGOING RESEARCH ACTIVITIES

Optimization of operating parameters to control the process performance

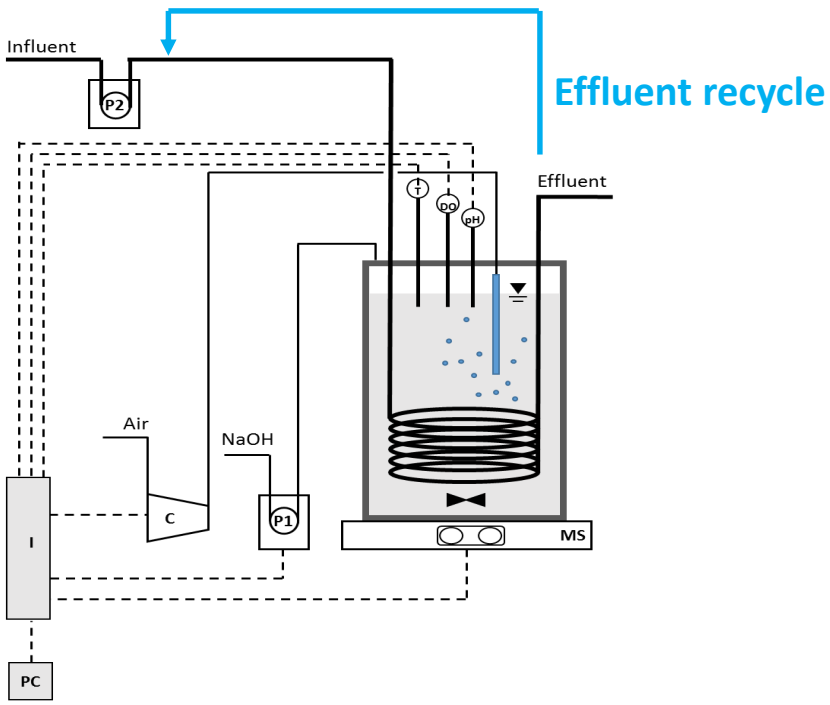
- ***Long-term operation***

Analysis of the process performance and polymer self-regeneration for times of the order of months



- ***Effluent recycle application***

Analysis of the system performance at different recycle ratios to verify the potential mitigation effect of the effluent recycle with increasing loadings



- ***Test on real industrial wastewater***

Verification of the hybrid technology

RECENT PUBLICATIONS

- Tomei M.C., Mosca Angelucci D. (2019). Enhancing biodegradation of toxic industrial wastewater in a continuous two-phase partitioning bioreactor operated with effluent recycle. Process Safety and Environmental Protection 124, 172-180.
- Tomei M.C., Stazi V., Mosca Angelucci D. (2018). Biological treatment of hypersaline wastewater in a continuous two-phase partitioning bioreactor: analysis of the response to step, ramp and impulse loadings. Journal of Cleaner Production, 191, 67-77.
- Tomei M.C. Mosca Angelucci D., Stazi V., Daugulis A.J. (2017). On the applicability of a hybrid bioreactor operated with polymeric tubing for the biological treatment of saline wastewater. Science of the Total Environment, 599-600, 1056-1063.
- Mosca Angelucci D., Stazi V., Daugulis A.J., Tomei M.C. (2017). Treatment of synthetic tannery wastewater in a continuous two-phase partitioning bioreactor: biodegradation of the organic fraction and chromium separation. Journal of Cleaner Production, 152, 321-329.
- Tomei M.C., Mosca Angelucci D., Daugulis A.J. (2017). A novel continuous two-phase partitioning bioreactor operated with polymeric tubing: performance validation for enhanced biological removal of toxic substrates. Journal of Environmental Management, 187, 265-272.
- Tomei M.C. Mosca Angelucci D., Daugulis A.J. (2016). Towards a continuous two-phase partitioning bioreactor for xenobiotic removal. Journal of Hazardous Materials, 317, 403–415.

Thanks for the attention