Improvement of biofilm formation in trickle bed reactors by surface modification of different packing materials

AUTEX

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Ghent (Belgium)

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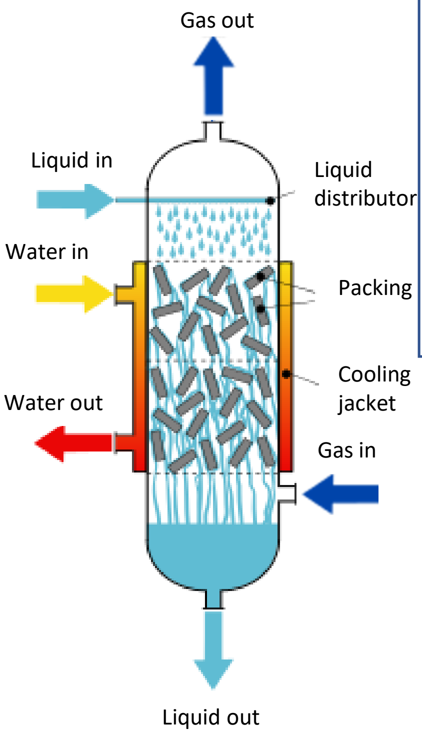
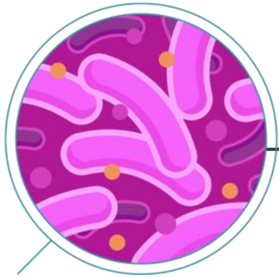
Introduction



Trickle bed reactor

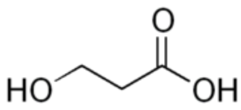
STAGE 1

STAGE 2



Cupriavidus necator

TARGET COMPOUND



3-Hydroxypropionic acid

STAGE 3

Acryilic deriv.
(Biopolymer)

To avoid overexploitation of natural resources

To reduce GHG (Greenhouse Gases) emissions

To find alternatives to currently used petroleum-based materials

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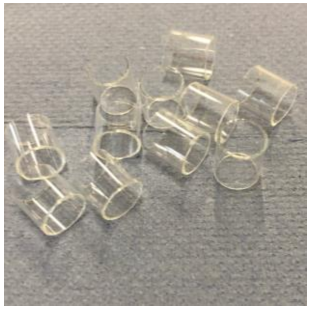
Packing materials in TBR

Packing materials are commonly used in TBR for adhesion and growth of bacteria

Parameters influencing the attachment, growth and biofilm formation:

- ❖ Electrostatic interaction between support and bacteria
- ❖ Surface area and surface roughness of the support
- ❖ Size and shape of the bacteria
- ❖ Hydrophobic or hydrophilic nature of the support and bacteria
- ❖ Availability of nutrients
- ❖ Shear forces in the bioreactor



RASCHIG RINGS – CONVENTIONAL PACKING MATERIAL

- ❖ Provide a large surface area within the reactor
- ❖ Random packing
- ❖ High economic cost

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Advanced packing materials

The aim of this research is to study innovative, efficient, environmentally friendly and low-cost packing materials, by analyzing their characteristics, bio-adhesion properties and growth of bacteria

Beech wood

Eucalyptus wood

Hard PU foam

Soft PU foam

HARDWOOD CHIPS

- ❖ Hardwood chips have vessels, higher density and higher concertation of lignin compared to softwood.
- ❖ Most types of bacteria are not able to degrade lignin.
- ❖ High surface energy, roughness and porosity.

POLYURETHANE FOAMS

- ❖ Reticular foam plastics, such as polyurethane foams, present a high porosity and large surface area.

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Advanced packing materials

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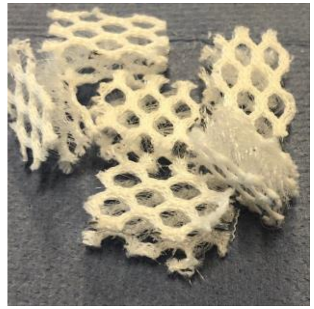

FIBROUS MATERIALS (PES TEXTILES)

- Three different configurations
- Large surface area and porosity

POLYISOCYANURATE (PIR) BASED FOAM

- Thermoset plastic
- Large surface area and porosity

POLYPROPYLENE PELLETS

- Have been found to provide good adhesion and biofilm growth properties

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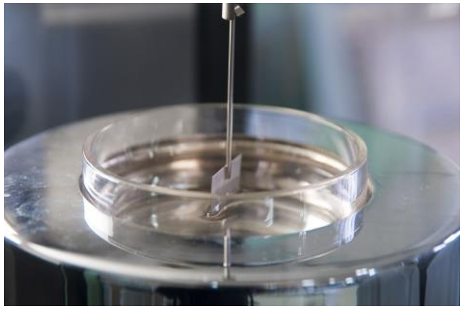
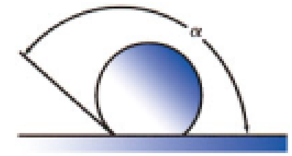
Wettability

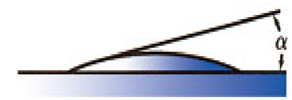


Tensiometer - Wilhelmy method

- WCA>90º - hydrophobic surface
- WCA<90º - hydrophilic surface



Bad wetting



Good wetting

Category	Contact angle
Raschig rings	58.2 ± 4.3º
Beech wood chips	64.1 ± 4.9º
Polyester 3D fabric	65.8 ± 8.6º
Polyester woven fabric	66.6 ± 0.5º
Polyester nonwoven	66.6 ± 0.5º
Eucalyptus wood chips	88.2 ± 3.7º
Soft polyether-polyurethane foam	88.8 ± 0.2º
Hard polyether-polyurethane foam	90.7 ± 1.7º

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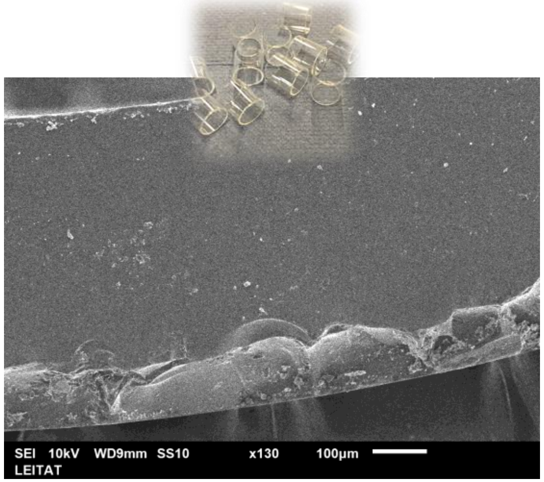
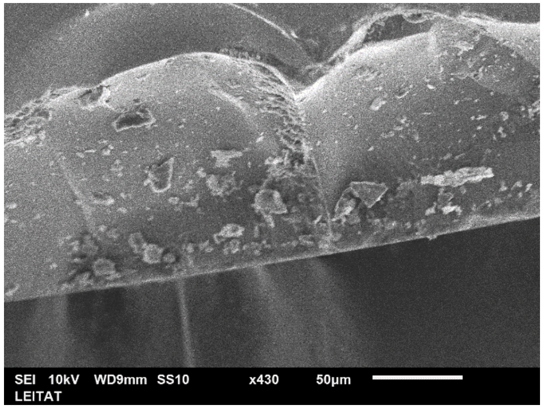
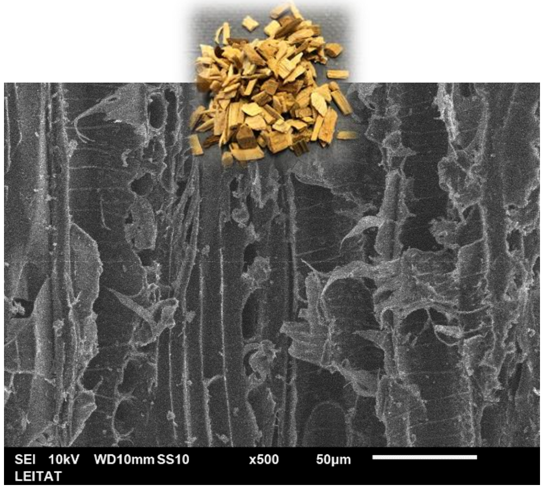
Morphology (SEM)

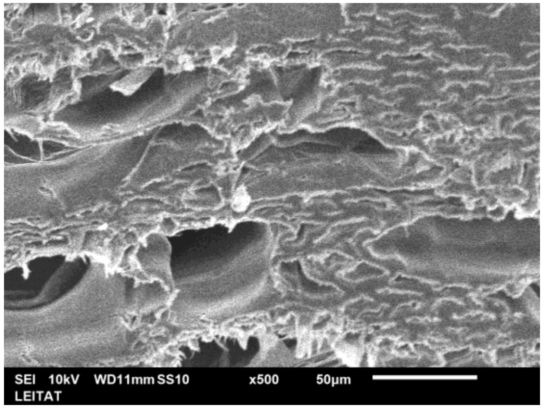
Raschig rings



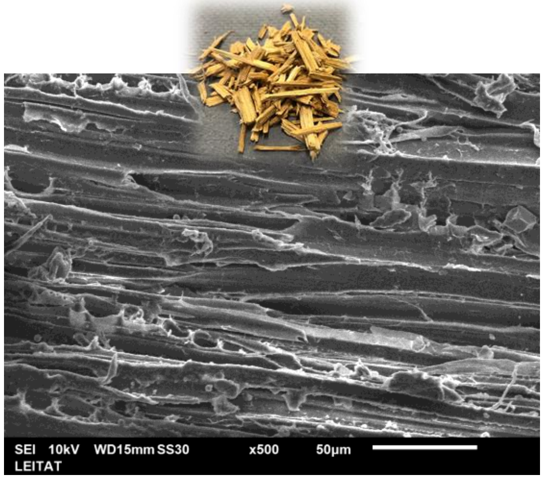


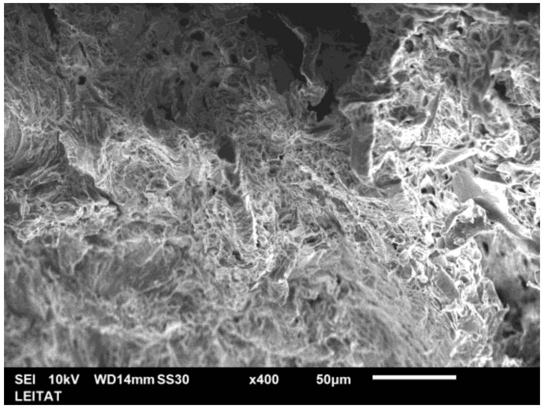
Beech wood





Eucalyptus wood





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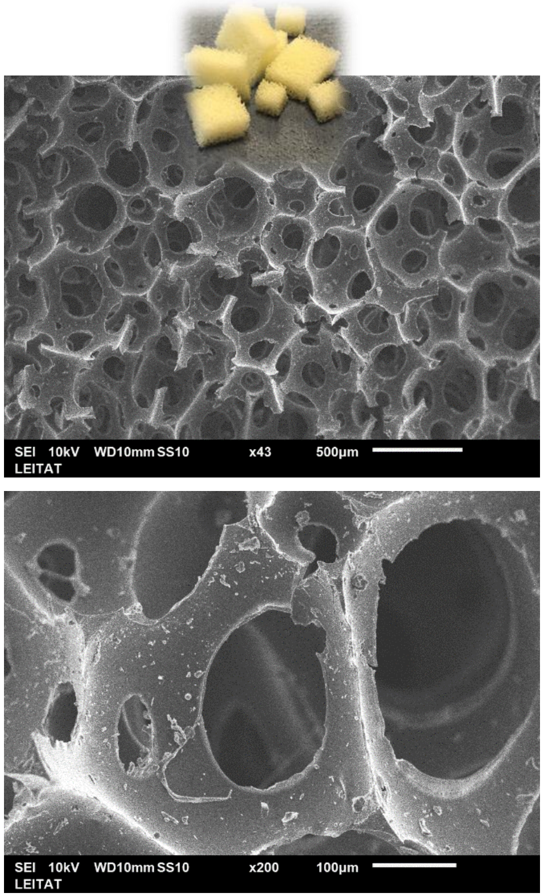
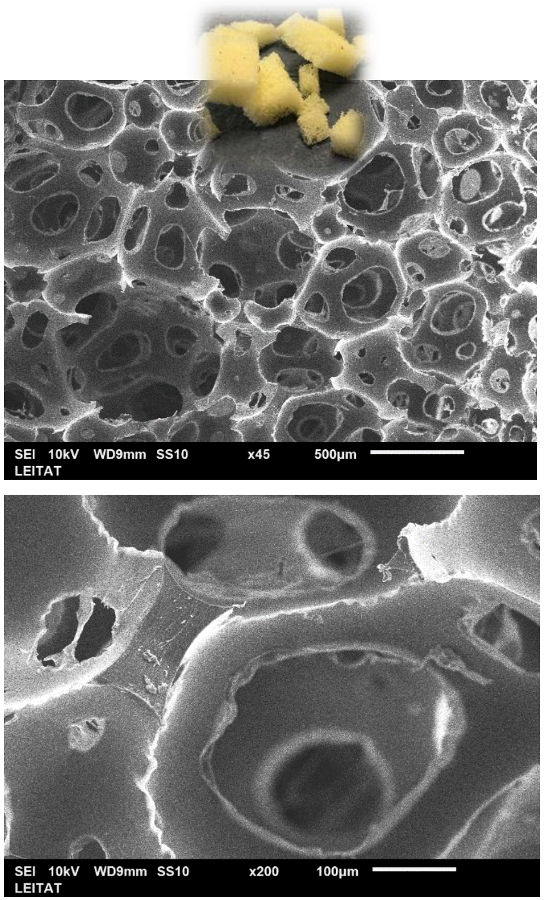
Morphology (SEM)

Foams

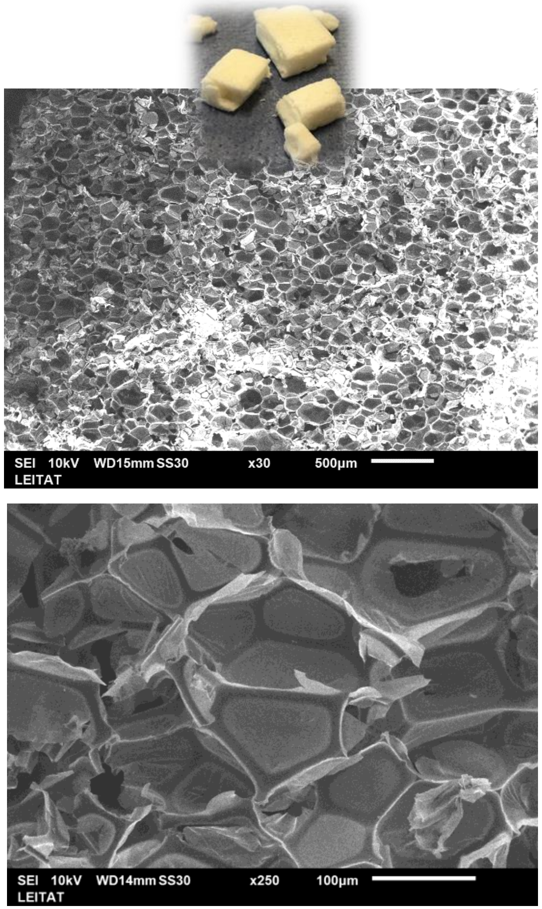
Hard PU



Soft PU



Polyisocyanurate



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Morphology (SEM)

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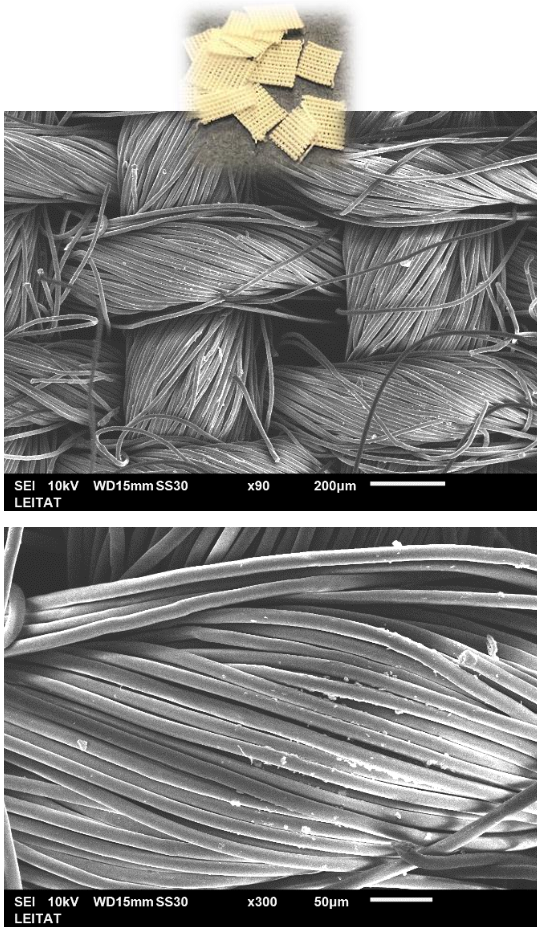
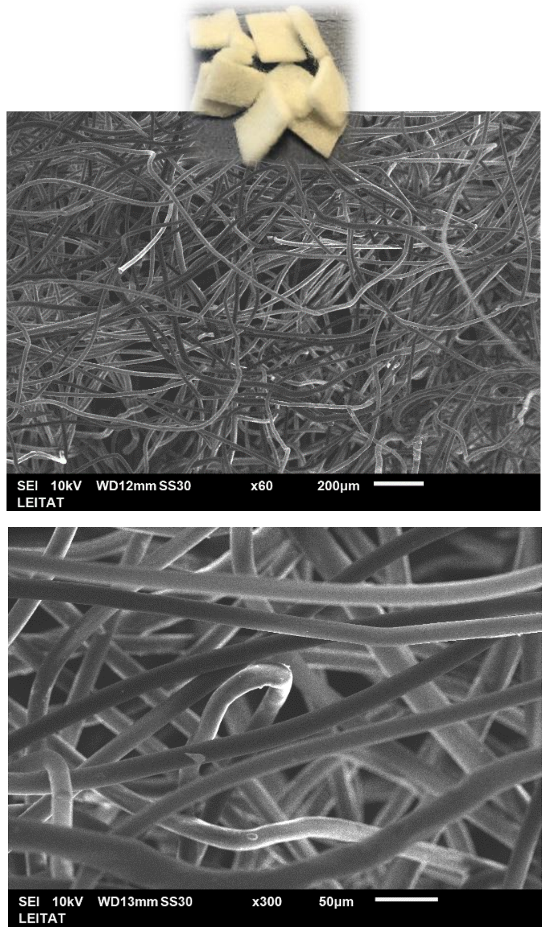
Polyester fabrics

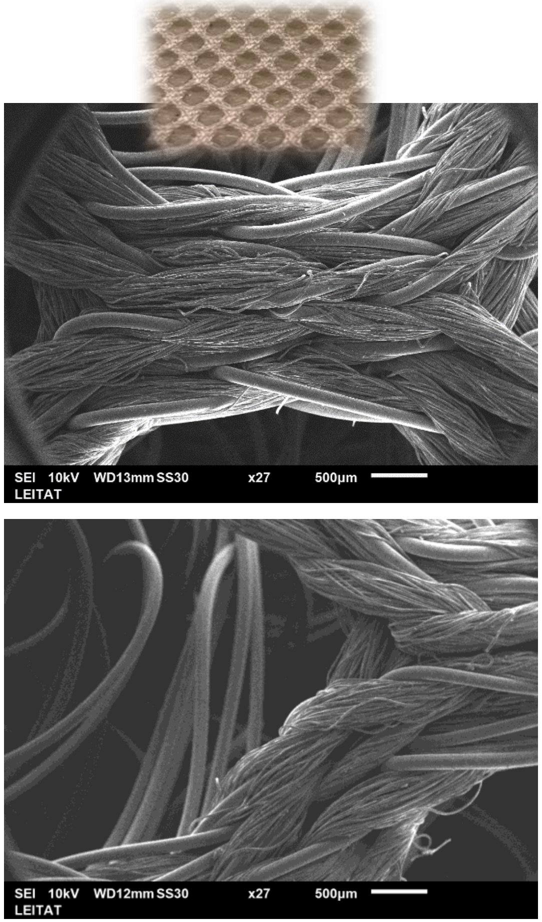
Woven



Non-woven



3D



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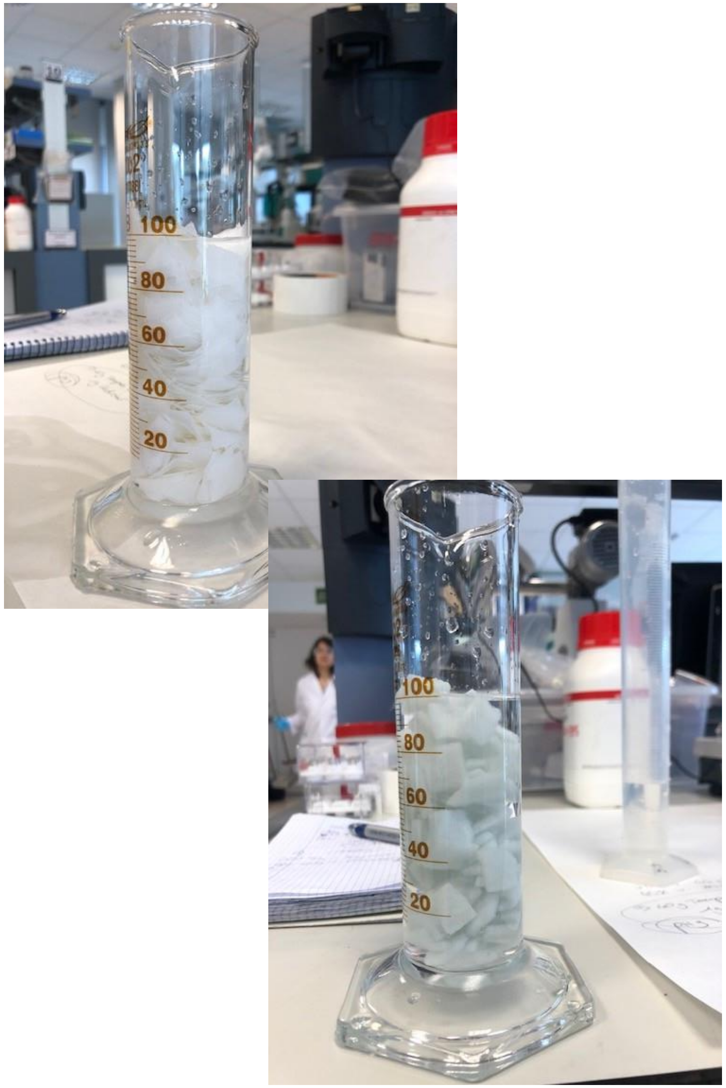
Apparent density

$$Apparent\ density = \frac{Material\ weigth}{Rector\ volume - Material\ volume}$$

Category	Apparent density (g/cm³)
Raschig rings	2,58
PES 3D fabric	2,09
PES woven fabric	1,16
PES nonwoven	1,00
Eucalyptus wood	0,99
PP pellets	0,92
Beech wood	0,77
Soft PU foam	0,098
Hard PU foam	0,072
PIR-based foam	0,032



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Bacterial adhesion and growth

Bacterial colonisation essay with potential advanced packing materials

1. Incubation of bacteria at 30ºC with rotational shaking during 24 hours.
2. Washing of the packing materials to remove non-adhered bacteria.
3. Recovery and quantification of the cells forming the biofilm.

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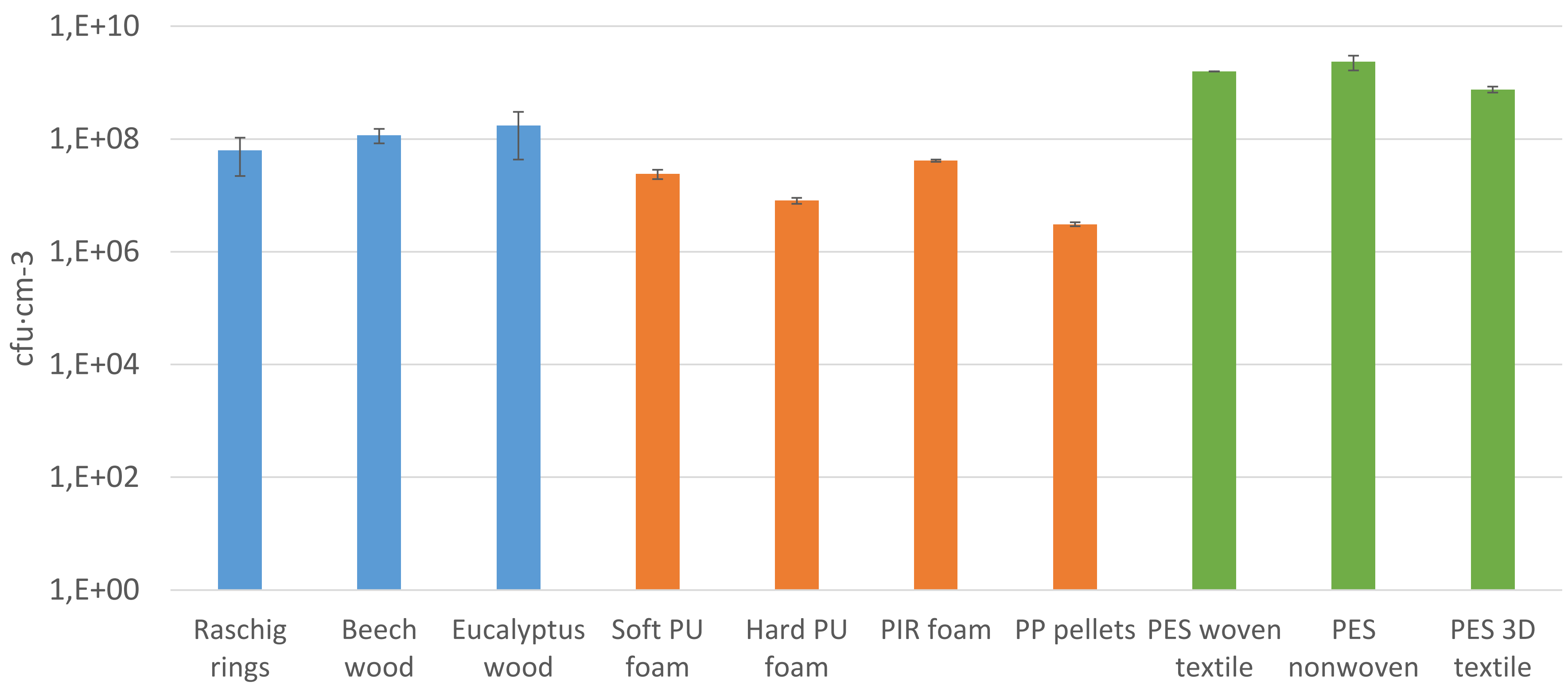
Bacterial adhesion and growth

BIOCON-CO_2



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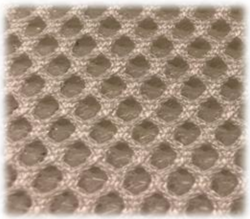
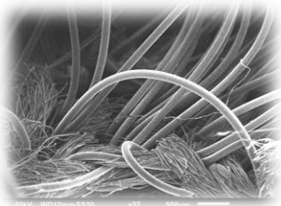
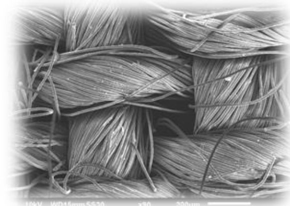
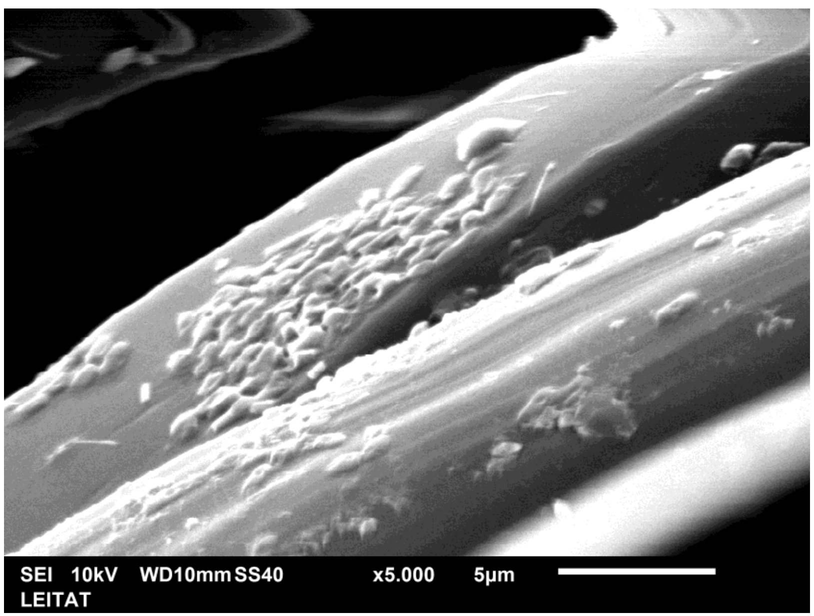
Bacterial adhesion and growth

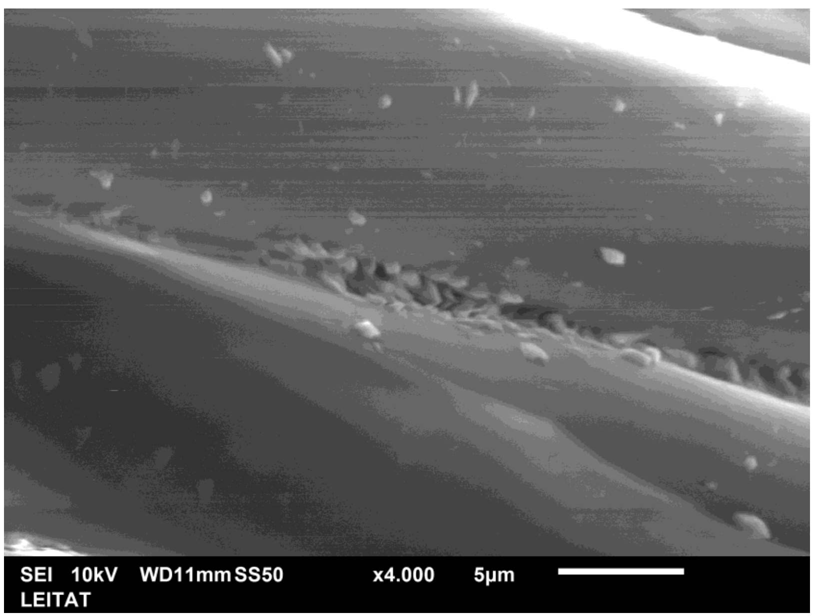
BIOCON-CO_2











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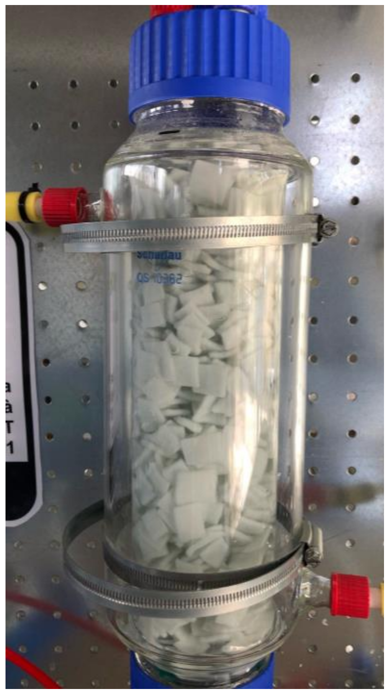
Behaviour upon water submersion

PES nonwoven		PES woven	
			
Before	After	Before	After

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Costs

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Category	Price (€/kg)	Apparent price (€/L)
Raschig rings	680	263
PIR-based foam	70	2333
Hard PU foam	53	757
Soft PU foam	53	530
PES 3D textile	16	7,7
PES woven textile	15	13
PES nonwoven	10	10
Eucalyptus Wood	2,0	2,0
PP pellets	1,8	2,0
Beech wood	0,6	0,8

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Final selection of packing materials

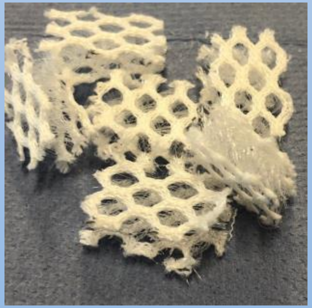
Conventional packing material

Alternative packing materials

Beech Wood

PES nonwoven

PES 3D fabric



✓ Adhesion of bacteria *C. necator* and biofilm formation

✓ Adaptability of the packing material inside the reactor

✓ Degradation suffered by the packing materials over time

✓ Accessibility to nutrients by the bacteria

✓ Cost of packing materials

PENDING: Biofilm survival over time and CO_2 absorption

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Plasma technology

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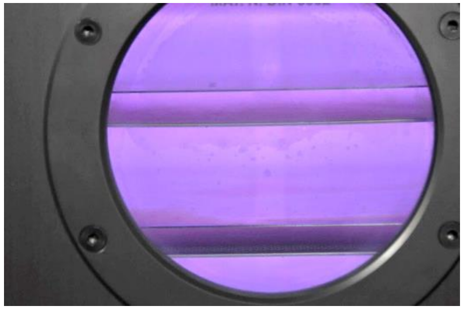
Plasma is a partially ionized gas composed of electrons, ions, photons, atoms and molecules, with negative global electric charge

Atmospheric pressure plasma

Low pressure plasma



Surface phenomena:

- ❑ Surface cleaning without modification of intrinsic properties
- ❑ Increased fibre surface roughness and surface area
- ❑ Increased surface energy to promote wetting
- ❑ Deposition of functional groups onto the surface
- ❑ Functional nano-coatings deposition (PECVD)

Advantages of plasma technology:

- ❑ Neither water consumption nor wastewater effluents;
- ❑ No chemical consumption;
- ❑ Drying and curing processes are not necessary;
- ❑ Well-controlled and reproducible technique.

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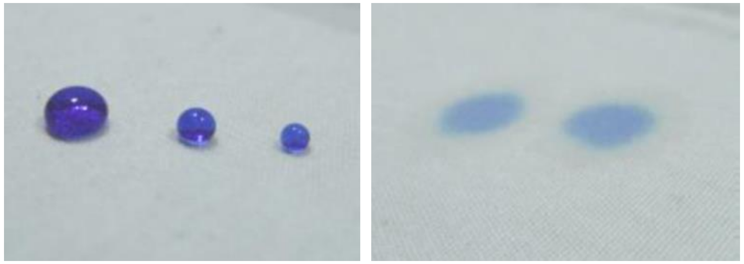
Plasma technology

Surface properties for promoting wetting and adhesion of biofilms:

- ✓ Hydrophobic/hydrophilic
- ✓ Surface charge
- ✓ Roughness
- ✓ Fluid dynamics on surfaces

High surface area for increasing gas and liquid sorption in bioreactors:

- ✓ Low-cost structured packing
- ✓ Increasing accumulated attached biomass
- ✓ Increasing bioreactor performance



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Conclusions

- 10 different packing materials have been evaluated by means of surface characterization, behaviour inside the reactor and biofilm adhesion and growth.
- 4 materials have been selected: Raschig rings (standard), PES nonwoven, PES 3D textile and Beechwood chips.
- Plasma treatments will be performed aiming to improve the surface properties of the packing materials and increase the biofilm formation, and thus the 3-HP production.
- The real performance of the packing materials in the TBR will be evaluated during the following months.
- Optimum packing materials with adapted surface properties will be obtained by the end of the project (May 2020).

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Thank You

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