Quantification of mesoscale structure monitored with Optical Coherence Tomography (OCT) helps to understand biofilm processes

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Biofilm structure in Gravity-Driven Membrane (GDM) filtration

Prototype of GDM system being tested in the field (Kenya).

Laboratory-scale GDM system with flow cell suitable for CLSM and OCT.
Biofilm structure in Gravity-Driven Membrane (GDM) filtration

Macro-scale: flux stabilizes but level of flux stabilization is changing

Lab-scale: Different biofilm structures are observed
Biofilm structure in Gravity-Driven Membrane (GDM) filtration

Objectives:

Linking filtration performances with the formation of different biofilm structures

Demonstrating that meso-scale monitoring and quantification of biofilm structure provide relevant information
Limited information is provided by micro-scale observation (CLSM)

Stable permeate flux (macro-scale)

CLSM observations (micro-scale)

Case 1:
Flux = 5-10 L/m²h

Case 2:
Flux = 3-6 L/m²h

Staining: SybrGold® for nucleic acids (in green) and reflection for particulate matter (in grey)
Optical Coherence Tomography (OCT) to monitor large biofilm structure?

Untreated OCT image (1 x 5 mm) of a biofilm developed on UF membrane surface during GDM filtration.
Optical Coherence Tomography (OCT) to monitor large biofilm structure?

OCT images:
4 x 4 x 1 mm
Scanning time: 1 min

CLSM:
750 x 750 x 150 mm
Scanning time: around 10 min
Meso-scale biofilm structure influences filtration performance

Permeate flux (macro-scale)

Case 1:
Flux = 5-10 L/m²h

Case 2:
Flux = 3-6 L/m²h

OCT observations (meso-scale)
Meso-scale biofilm structure influences filtration performance

Permeate flux (macro-scale)

Case 1:
Flux = 5-10 L/m²h

OCT observations (meso-scale)

Case 1: 500 µm

Take home message #1:
OCT is suitable to monitor meso-scale biofilm structure AND complementary to CLSM

Case 2:
Flux = 3-6 L/m²h

Case 2: 500 µm
Quantification of OCT images

#1 Image recording using OCT

#2 Membrane detection (automatic or manual). If automatic, filtering + maximum intensity detection

#3 Thresholding (Triangle method) Zack et al., 1977

#4 Cropping and re-sizing (Wagner et al., 2010)

#5 Quantification after outlier detection
Quantification of OCT images reveals changes in the biofilm structure.
Meso-scale biofilm structure influences filtration performance

Mean thickness: 50 µm

Mean thickness: 150 µm
Meso-scale biofilm structure influences filtration performance

Take home message #2: Quantification of OCT images helps to objectively distinguish biofilm structure

Mean thickness: 50 µm

Mean thickness: 150 µm
How does a heterogeneous biofilm structure influence the flux?

Case 1

Coll. with University of Notre-Dame (K. Martin and R. Nerenberg)
Combining OCT with COMSOL® explains flow distribution...

Case 2

Coll. with University of Notre-Dame (K.Martin and R.Nerenberg)
Both numerical and experimental results confirm that the more heterogeneous the biofilm structure, the higher the permeate flux.
Monitoring and quantification of meso-scale biofilm structure using Optical Coherence Tomography provides relevant information to better understand biofilm systems, e.g., GDM filtration. Greater potential of OCT when combined with complementary analytical tools and integrated in a multi-scale approach.