A new attempt to measure biofilm rheology by optical coherence tomography

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Whereas the activity or function of biofilms is mainly driven by the microbial community hosted in a polymeric matrix on the one side the physical properties of microorganisms and polymeric matrix mainly influence shape and mechanical stability of biofilms. The latter thereby has a huge influence on mass transfer as well as detachment processes at the bulk biofilm interface. Biofilm rheology has been studied widely, often on-line by microscopy. In the study presented simple stress-strain and creep experiments were conducted on multi-species biofilms grown in a flow cell at laminar flow. Structural deformation of the biofilm caused by hydrodynamic shear stress (τ_w) was visualized by means of optical coherence tomography (OCT). OCT is an emerging non-invasive imaging technique, which measures a depth profile (A-scan) from translucent tissues. Consecutive A-scans provide a cross section of biofilms (B-scan), which can be combined to a volumetric representation (C-scan). Moreover, C-scans can be analyzed to determine biofilm characteristics such as porosity, roughness and distribution of cavities. OCT has been introduced into biofilm research due to its ease of use and the capability to monitor online in situ and non-invasively the biofilm structure at the mm-scale (mesoscale). The biofilm structure can be visuali -range, overcoming the disadvantage of measuring only local biofilm properties at the microscale.

In a new attempt on-line monitoring by means of acquiring OCT B-scans along the flow direction was used to measure biofilm strain and creep. Biofilms were grown in 12 cm long flow cells made of PMMA with a cross-section area of 2 × 1 mm^2 at defined hydrodynamic and nutritional conditions. By changing the flow velocity, hydrodynamic conditions were altered to expose biofilms to shear stresses over a wider range. Biofilms were grown at low shear stress τ_w= 0.01 N/m^2 (Re = 3) and shear stress experiments were conducted ranging from τ_w = 0.01 N/m^2 to τ_w = 2.9 N/m^2 (Re = 860).
At τ_w = 1.6 N/m^2 ε = f deformation was α = 3°. After each shear test the biofilm returned into its original shape showing an elastic response. Measuring displacement within biofilms by confocal laser scanning microscopy (CLSM) is only possible by addition of fluorescent particles (Stoodley et al., 1999). With the help of OCT it is now possible to visualize structural changes within the whole biofilm, closing the gap between microscopic techniques and mechanical measurements such as spinning disc rheometry (Towler et al., 2003) or fluid dynamic gauging (Möhle et al., 2007). OCT offers new possibilities for monitoring biofilm growth and will help to gain a deeper understanding of biofilm rheology at hydrodynamic stress without addition of interfering substances such as fluorescent substances.

Reference:

Möhle, R. B., Langemann, T., Haesner, M., Augustin, W., Scholl, S., Neu, T. R. & Horn, H. (2007). Structure and shear strength of microbial biofilms as determined with confocal laser scanning

microscopy and fluid dynamic gauging using a novel rotating disc biofilm reactor. Biotechnology and Bioengineering, 98(4), 747 755.
Stoodley, P., Lewandowski, Z., Boyle, J. D., & Lappin-Scott, H. M. (1999). Structural deformation of bacterial biofilms caused by short-term fluctuations in fluid shear: an in situ investigation of biofilm rheology. Biotechnology and Bioengineering, 65(1), 83 92.
Towler, B. W., Rupp, C. J., Cunningham, A. B., & Stoodley, P. (2003). Viscoelastic properties of a mixed culture biofilm from rheometer creep analysis. Biofouling, 19(5), 279 85