

Rheological properties of biofilms: steady and transient shear flow modeling

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ABSTRACT

Biofilms are considered as microbial communities attached to a surface where they grow as fixed films and interact with the media through the phases that flows over them. Biofilms form complex structures containing mainly microorganisms, nucleic acids, proteins, extracellular polymeric substances (EPS) (Sutherland, 2001) which provide them of specific mechanic properties (Wilking et al., 2011). The shear stress caused by the fluid flow over fixed biofilms is a factor of paramount importance which influences their development (growing and detachment) and, hence, affecting the system operation. A deeper knowledge in the characterization of the effect of flow on biofilms development could allow establishing rigorous models able to predict a closer behavior to real systems.

The aim of this study was to investigate extensively the rheological properties of heterotrophic biofilms present in bioreactors by performing rheological tests and models development. Considering a viscoelastic behavior, a detailed experimental program was accomplished to test the response of biofilms under steady shear, oscillatory and transient measurements. To develop a complete characterization, suspended biomass (SB) samples were also analyzed, comparing their rheological behavior with that obtained from the biofilms, i.e. fixed biomass, under different flow conditions.

In the steady shear mode, equilibrium flow curve measurements were conducted with controlled shear stress and raising it stepwise. In the oscillatory shear mode, amplitude sweep test was performed to determine the effect of shear stress on G' and G'' , determining the linear viscoelastic regimen (LVR) with a tolerance of 10% for the strain limit value. In the transient shear mode, shear creep tests were performed by applying a constant shear stress inside the LVR (40 Pa) and measuring shear strain (γ) over time.

Biofilms (32.6 and 34.5 g VSS L⁻¹) and suspended biomasses (from 8 to 43 g VSS L⁻¹) were analyzed in the steady shear flow (Figure 1). Their shear-thinning behavior with a yield stress was identified, fitting the data results with Herschel-Bulkley model (Mezger, 2006). These results allowed us to model their rheological behavior as non-newtonian fluids, and to correlate the rheological parameters in function of the concentration samples. In oscillatory shear flow analysis of biofilms and SB samples (Figure 2A), the elastic behavior dominated the viscous one inside the LVR, showing

their gel character, but with some inequalities in their structure and viscoelastic properties. Similar behavior was also observed under transient shear flow test (Figure 2B), where the deformation of biofilm was much greater than in the SB samples. The Burger model (Towler et al., 2003) described rightly the strain of both samples.

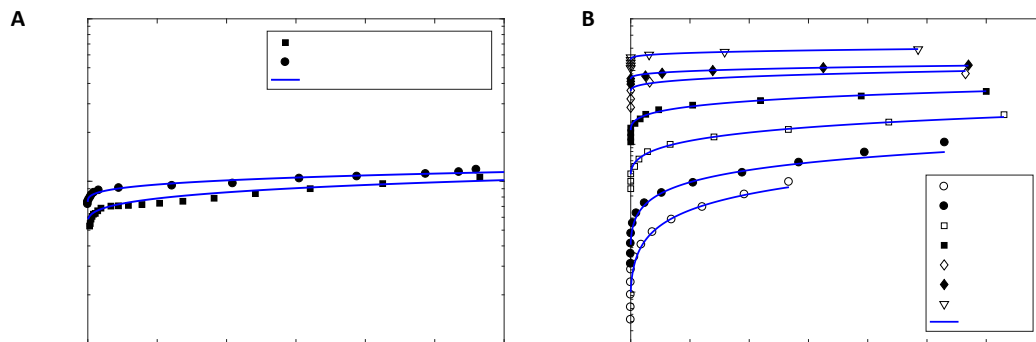


Figure 1. Flow curves of biofilms (A) and suspended biomass (B) samples at different concentrations. Symbols are experimental data and solid lines represent models fitting.

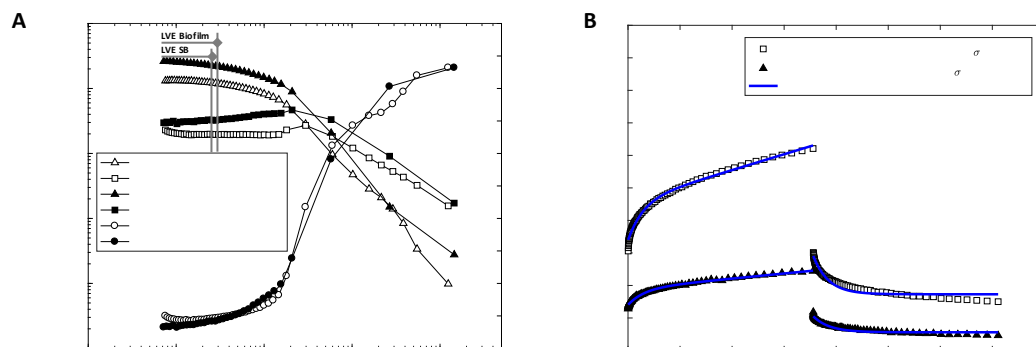


Figure 2. Dynamic properties as function of applied strain (A) and creep and recovery at applied shear stress for 180 seconds and then removed (B) for biofilm and suspended biomass samples.

CONCLUSIONS

This work provides models for the description of the biofilm as a pseudo-plastic fluid. This characterization allows us to define the biofilm as an independent phase, avoiding the general procedure of associating the biological reactions to the liquid phase, and defining a multiphase system where the hydrodynamics can interact with the biological component. In addition, some dissimilarities between biofilms and SB samples were detected in function of shear flow conditions. Therefore, the large amount of EPS in the biofilm samples have a significant role in their deformation, affecting considerably their internal structures and viscoelastic properties, as suggested by Wilking et al., (2011).

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