Real-time rheology of actively growing *Staphylococcus aureus* bacteria

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Scope

Objective: Characterization of the rheological response of a bacterial planktonic culture under a steady-state shear flow and a dynamic shear flow during the evolution of growth with time.

System: *Staphylococcus aureus*, a human pathogenic bacterium.

Experimental Techniques: Optical density monitoring (OD_{620nm}); Platting - colony forming units determination (cfu/ml); Optical microscopy; Rheology.

Evidence: A rich viscoelastic behaviour was observed: the shear viscosity changes dramatically as a consequence of the bacteria activity, allowing to evoke the existence of a percolation phenomenon and to consider these behaviours compatible with the soft glassy material model – SGM[2].

Results

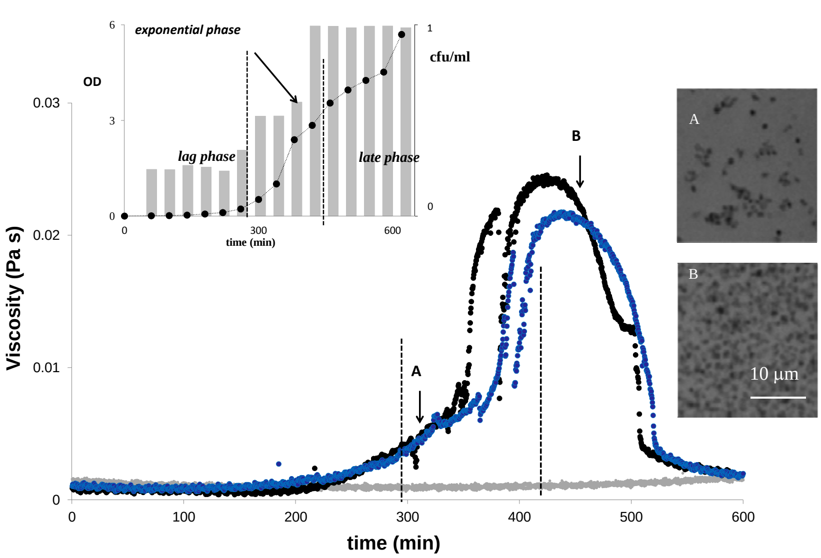

Figure 1: S. aureus culture steady-state shear growth curve, measured at a constant shear rate of 10 s^{-1}; gray line: culture medium; black and blue symbols: S. aureus culture (representative curves); A and B: optical microscopy images obtained during the growth curve at, respectively, 300 and 470 min. Inset: S. aureus culture characterized by optical densities (OD_{620nm}) (full symbols) and the population's colony-forming units, in arbitrary dimensions (cfu/ml) (bars); dashed lines separate distinct growth phases: lag, exponential, and late phases. All measurements were performed at 37 ºC.

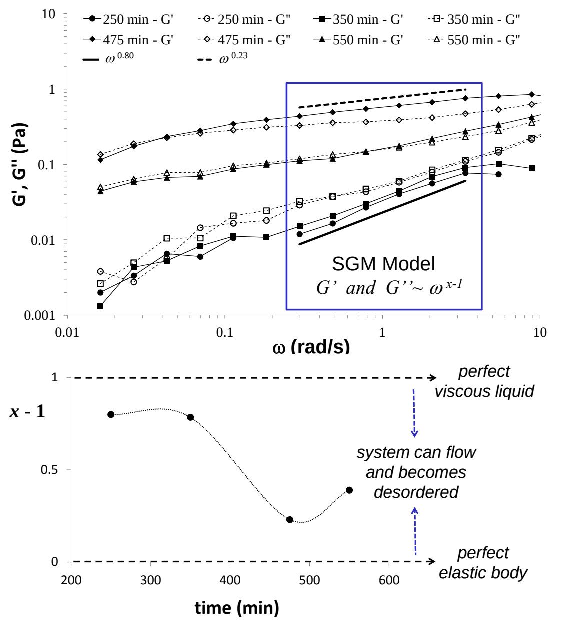

Figure 2: Up: Representative oscillatory shear flow experiments of the S. aureus culture aliquots: elastic modulus G' and viscous modulus G" dependence on the angular frequency ω; measurements were performed at 20 ºC. Solid and dashed lines correspond to the power laws of $\omega^{0.80}$ and $\omega^{0.23}$, respectively, as guides to the eye. Down: Evolution of the power-law exponent $(x - 1)$ vs time.

Conclusions

It was possible to characterize in real-time the mechanical behavior of an actively growing *S. aureus* culture by rheology: the viscoelastic properties of the *S. aureus* culture suffer extensive changes over time.

The shear viscosity changes dramatically as a consequence of the bacteria activity. In the early stages of growth (lag and exponential phases), the viscosity increases by about a factor of 20, presenting several drops and full recoveries. This allows us to evoke the existence of a percolation phenomenon. Eventually, as the bacteria population reaches a final stage of evolution, fulfilling the sample volume, there is a decrease in the viscosity close to its initial value, probably due to a change in the physiological state of the bacteria, most likely a decrease in the adhesion properties. The viscous and the elastic moduli present power law behaviours compatible with the "soft glassy materials" model, which exponents are dependent on the bacteria growth stage.

It is clear that *S. aureus* cellular activity, at 37 ºC, through the development of cell self-organized structures, leads to phenomena which are not observable by common microbiological methods but result in striking alterations of the rheological properties of the cell suspension.

Some References:

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[2] P. Sollich, F. Lequeux, P. Hebraud, and M. E. Cates, *Phys. Rev. Lett.,* 78, 2020,1997.

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