Particle Incorporation into Bacterial Cellulose in a Rotating Disk Bioreactor

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Abstract

Bacterial cellulose produced by *Gluconacetobacter xylinus* (formerly *Acetobacter xylinum*) in a rotating disk bioreactor (RDB) is preferentially found on the rotating disk, not in the bulk media, and thickens in the axial direction. It has been found that 25-250μm particles suspended in the growth media are incorporated into the cellulose matrix. Biocomposite materials of particles in a bacterial cellulose (BC) matrix have applications in medical wound dressings, tissue engineering scaffolds, and paper batteries. Here we improve on the RDB design, successfully reducing the growth of stray BC in the reactor chamber that is unaffiliated with the disk, achieve near-perfect particle mixing, and adopt direct biocomposite characterization techniques: gravimetric analysis and photomicroscopy. These techniques support each other with gravimetric analysis is a coarse high throughput method used primarily is experimental design. Photomicroscopy is a more precise measurement method, but is much more time intensive and is used to assess incorporated particle concentrations in BC products. Particle incorporation in the improved apparatus is verified with both characterization techniques. A three-step mechanism of particle incorporation is presented with theoretical foundation and experimental support. The dominant forces sequentially acting on the particles describe the three steps of the mechanism: hydrodynamics and diffusion across a boundary layer; particle-surface non-covalent interactions; and mechanical entrapment by the cellulose fibers. The proposed mechanism predicts negatively charged particles will be spatially incorporated at a rate proportional to the tangential velocities on the disk face and positively charged particles will be incorporated uniformly of the disk surface at a rate proportional to the rotational rate. Experimental results for all particles show a discontinuity in the radial distribution of incorporated mass profiles in the BC products. The mass incorporated at the outer edge of the disk is much greater than anywhere in the disk interior. Repeated visualization of tracer particles at various speeds and disk-to-chamber aspect ratios reveal that the surface bound boundary layer breakdown at disk withdrawal from the liquid phase generates eddies at the disk edge that draw particles into an aggregate cloud greatly enhancing uptake. Numerical analysis and integration of an empirical correlation of thickness of the entrained fluid film attached to the disk surface in the air-phase is proposed to refine the analytical result from infinite plate

withdrawal theory. The empirical correlation promises to capture the influence of gravity on the fluid film and be a more realistic starting point for evaluating the mass profiles of experimental BC products. Finally a set of experiments and a detailed photomicroscopy procedure is presented to visually confirm the rotational rate or tangential velocity dependence on particle uptake.