Comprehensive Modeling of Light-limited Algae Growth Rate in a Taylor Vortex Photobioreactor: From Hydrodynamics, Radiation Transfer to Algae Growth Model

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The phenomenon that microalgal biomass productivity and light utilization efficiency can be dramatically increased by causing them to experience light/dark cycles with frequencies greater than 1 Hz, referring to as the flashing light effect, has long been discovered. However this phenomenon has not been effectively utilized in most algae photobioreactor designs. In our previous experimental studies, we demonstrated that coherent flow structures known as Taylor vortices can be used to efficiently generate highly periodic light/dark cycles with tunable frequencies greater than 1 Hz, which in turn produce significant increases in biomass productivity. In this paper, a comprehensive quantitative model of algae growth in Taylor vortex algal photobioreactors is reported. First, a numerical method for solving the multidimensional radiative transport equation is developed to compute spectral light distribution in the reactor, accounting for light absorption and scattering by algae cells. Second, computation fluid dynamics (CFD) and Lagrangian particle tracking simulations are performed to provide statistically meaningful data for microorganism trajectories in the reactor. Combining these two, a detailed description of the history of algae exposure to photosynthetically active radiation is obtained, which in turn is used as the input to an algae growth model accounting for the flashing light effect to predict the overall productivity of the reactor at different operating conditions. Lastly, the model is validated with our experimental data. We demonstrated that our numerical model can be used to significantly enhance algal photobioreactor design and scale-up.