**Couette-Taylor photo-bioreactor: A perfect tool to explore both**

**the impact of hydrodynamic mixing and shear stress on microalgae cells**

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Biotechnology with microalgae and photo-bioreactor (PBR) design is nowadays regaining attention thanks to the emerging projects of algae biofuels and CO₂ sequestration. However, there neither exist reliable methods, nor programming software for modelling, simulation and control of microbial growth in PBR [4]. Nevertheless, the development of a CAD software for the photo-bioreactor design is the natural goal of many researchers in the area of bioreaction engineering.

Modelling in a predictive way the photosynthetic response in the three-dimensional flow field in PBR seems today unrealistic, because the global response depends on numerous interacting intracellular reactions, with various time-scales. The physiological state of any cellular system and its impact on growth and product formation is the result of a complex interaction between the extracellular environment and the cellular machinery. The design of PBR in which microalgae cells function as factories as well as the prediction of suitable PBR operating conditions is further complicated because of the dynamic variations of the extracellular environment. Consequently, a quantitative description of these phenomena should rest upon the two interlinked aspects of structured bioprocess modelling: (i) complex interaction of the functional units within each cell, (ii) structure of the abiotic phases of PBR.

Our main goal, in this contribution, is to describe the development of the mathematical model of microalgae growth in a general PBR as well as the design of suitable experiments in order to identify the impact of hydrodynamic mixing and shear stress on microalgae cells. For this purpose, we designed the laboratory PBR based on the Couette-Taylor flow, the so-called Couette-Taylor photo-bioreactor (further CTBR). Since 1953 [2], it is known that CTBR is well suited for microalgae culture: mainly because of the mass transfer enhanced, and the ordered mixing inducing light-dark cycles and the so-called flashing light effect [2, 3, 9].
In our previous works we studied an adequate multi-scale lumped parameter model which well describes the principal physiological mechanisms in microalgae: photosynthetic light-dark reactions and photoinhibition [6, 7, 8], and in [5] we presented how to construct a distributed parameter model consisting mainly in determination of hydrodynamic dispersion coefficient as function of space coordinates. This paper deals with the model improvement (mainly incorporating the effect of hydrodynamic shear stress), calibration and validation, based on laboratory experiments carried out in our CTBR.

The main advantage of CTBR, as a device for model calibration and validation, is that the light-dark cycles distribution, being the principal extracellular stimulus, is simply depending on two factors: (i) cell trajectories (i.e. on radial dispersion coefficient depending itself on the inner cylinder angular velocity), and (ii) on the scalar field of irradiance. In some flow regimes, based on [1], light-dark cycles distribution in CTBR could be even computed analytically. Conversely to the light regime, little is known about the effect of shear stress applied on cells. While the CTBR reported in [2] reached only limited number of revolutions per minute (up to 475 rpm), showing monotonically increasing growth with the increasing angular velocity, our CTBR is equipped by a control permitting a gradual increase of angular velocity up to 1000 rpm. Thus it will serve to identify the biological responses in a wide interval of flow regimes, starting from the Couette flow and ending in the turbulent Taylor vortex flow. We shall report data illustrating the case when the further increase of angular velocity causes the growth decay and even morphological damage due to the detrimental influence of shear stress on typical strains of unicellular microalgae Scenedesmus sp., see Fig. 1. In order to deeply investigate this phenomenon and to incorporate it into our model, we have designed both ‘non-destructive’ long-term experiments and ‘destructive’ short-term experiments which show the suitability of the Couette-Taylor photo-bioreactor to explore both the impact of hydrodynamic mixing and shear stress on microalgae cells.

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Figure 1: Microalgae cells of Scenedesmus sp. cultivated under different operating conditions in the Couette-Taylor photo-bioreactor, Institute of Physical Biology, University of South Bohemia, Nové Hrady, Czech Republic. Left: Inner cylinder angular velocity $\Omega = 0$ rpm (mixing is provided by the fine bubble aeration only); Right: $\Omega = 1000$ rpm (after 1 hour of excessive shear rate, the morphological changes became clearly visible).

References


