# MODELING AND SIMULATION OF MICROALGAE GROWTH IN A COUETTE-TAYLOR BIOREACTOR

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## 1 INTRODUCTION

A reliable model of microalgae growth is of paramount importance for photobioreactor (PBR) design, control and eventually PBR performance optimization. Nevertheless, even having an adequate lumped parameter model (LPM) of microalgae growth, another serious difficulty resides in the description of microorganism growth in a distributed parameter system (as PBR) where relevant variables, e.g., the irradiance and flow field, are distributed heterogeneously. Further, we propose a reliable methodology for PBR modeling and design which is based on integration of the CFD code ANSYS Fluent with a photosynthetic reaction kinetics. In order to validate our approach, a laboratory Couette-Taylor bioreactor, see Fig. 1, is used in a simple case study.

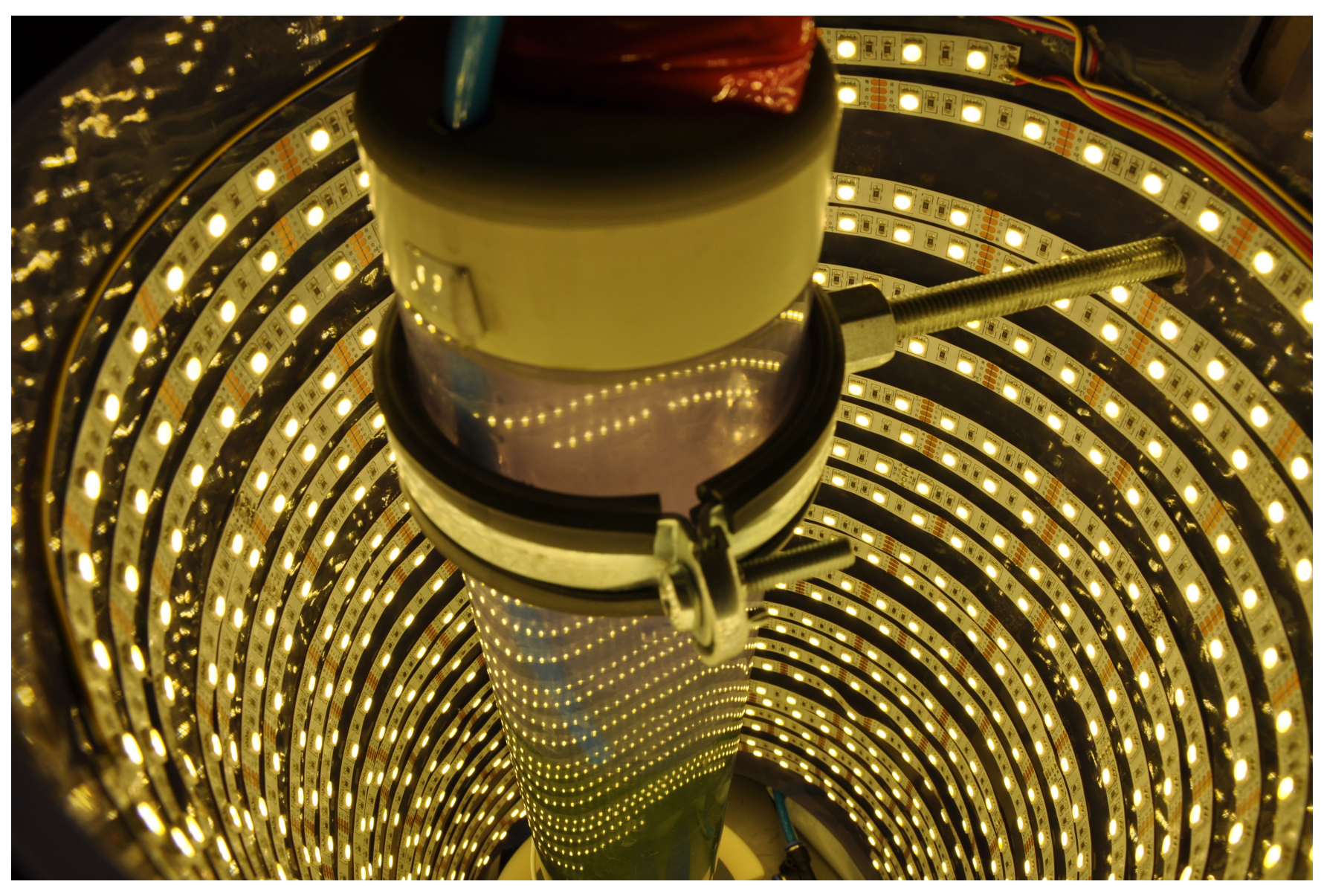

Fig.1: Couette-Taylor bioreactor illuminated by an arrangement of LED, University of South Bohemia, FFPW, Institute of Complex Systems, Nové Hrady, CZ.

## 2 MODEL DEVELOPMENT

### 2.1 Governing equations of algal growth – LPM

The photosynthetic microorganisms growth is usually modeled as the steady-state light response curve (so-called *P–I curve*), which represents the microbial kinetics (either of *Monod* or *Haldane* type). However, in order to describe some dynamic phenomena, e.g., the flashing light enhancement (Davis, 1953), a dynamic model is needed. The phenomenological three-state model of photosynthetic factory proposed by Eilers & Peeters (1993) and further developed by Rehák et al. (2008) was chosen because it correctly describes the principal physiological mechanisms: photosynthetic light-dark reactions and photoinhibition, see Fig. 2 below.

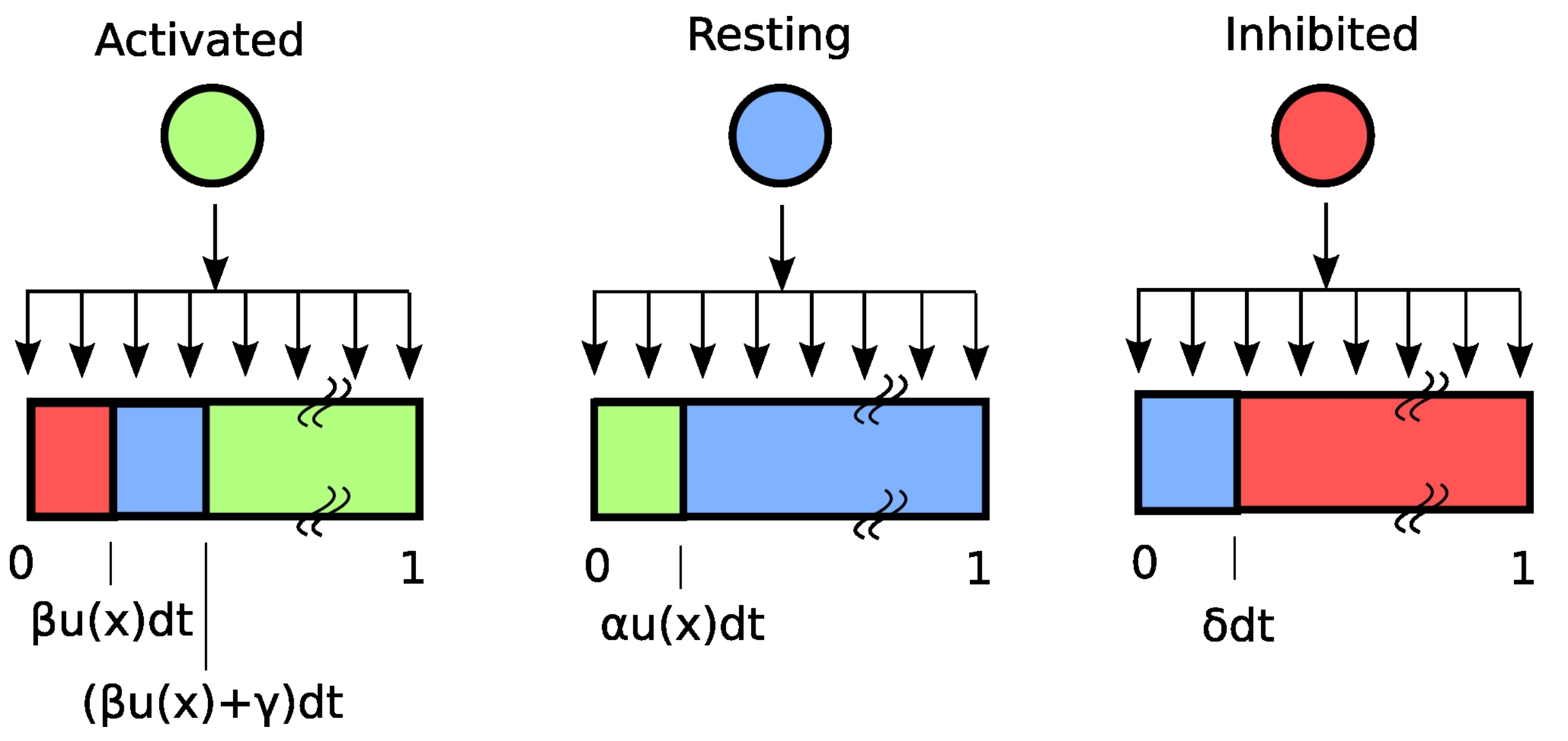

Fig. 2: Model of photosynthetic factory (PSF model) by Eilers & Peeters (1993), terms below the rectangles indicate the probability of respective transitions between states, where $\alpha, \beta, \gamma, \delta$ are model parameters, and $u(x)$ is irradiance level (dependending on spatial coordinate $x$). The spatiotemporal average of the activated state is related with specific growth rate.

### 2.2 DPM of algal growth – Eulerian (PDE based) approach

Systems with distributed parameters are described either using a **Lagrangian approach**, i.e., trajectories of individual microalgae within a PBR are determined and consequently the resulting irradiance history (in form of a distribution) is used as the stochastic input for an ODE (LPM), or **Eulerian approach**, i.e., by means of partial differential equations (PDE). Here, we describe a PBR as following Convection-Reaction-Diffusion (Dispersion) System, when for the reaction term the PSF model with order reduction (to fast dynamics only) was used, see Čelikovský et al. (2010):

$$\frac{\partial c_A}{\partial t} + \nabla \cdot (\vec{v} c_A) - \nabla \cdot (D \nabla c_A) = -k(c_A - c_{Ass})\,, \tag{1}$$

where $c_A$ is cell-in-state-A(activated)-concentration (unit: cell m$^{-3}$), $\vec{v}$ represents the velocity field, $D$ is the hydrodynamic dispersion coefficient and $k$ (unit: s$^{-1}$) is the rate at which the concentration $c_A$ is approaching to its steady-state value $c_{Ass}$ depending on external input (forcing) $u$, e.g., $k(u) = \theta_1(u(x) + \theta_2)$. According to the exponential attenuation in cylindrical coordinates, see Cornet et al. (1995), $u(r) = \frac{R\ u_1}{r}\frac{\cosh \kappa \frac{r}{R}}{\sinh \kappa}$, where $u_1$ is the incident irradiance on the outer CTBR wall ($r = R$), $R$ and $r_0$ are the outer and inner cylinder radii, respectively, $\kappa$ is the dimensionless attenuation coefficient defined as follows: $\kappa := \frac{\ln(2) R}{r_{1/2}}$, and $r_{1/2}$ is the length interval making diminish the intensity of light to one half (in rectangular geometry). The velocity field $\vec{v}$, needed in PDE (1), is reached as the solution of the Navier-Stokes equation system, e.g., by commercial CFD code ANSYS Fluent, see Fig. 3.

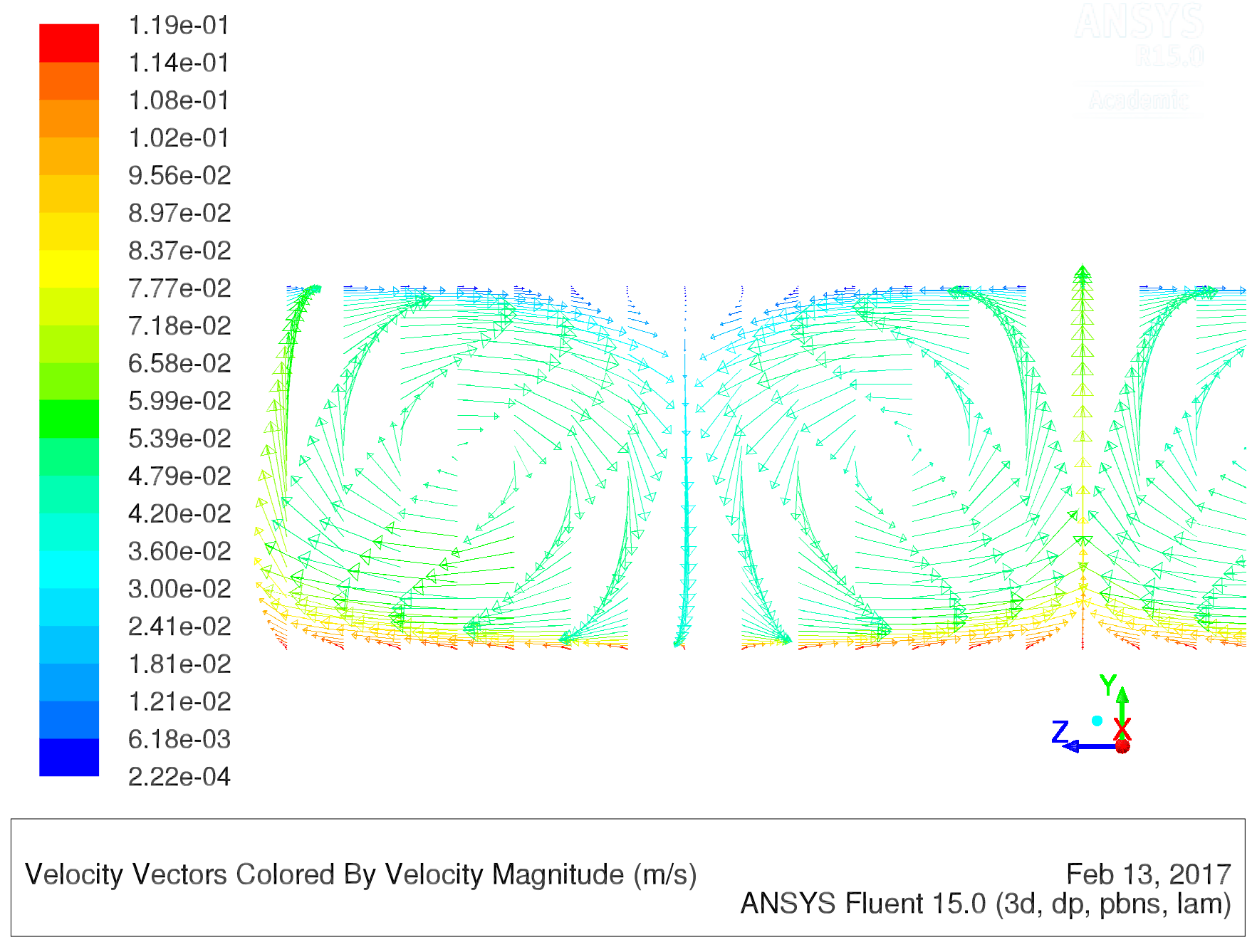

Fig. 3: Fluid flow velocity profile in the axial section of the laboratory CTBR calculated by CFD code ANSYS Fluent 15.0 (for the inner cylinder angular frequency $\omega$ = 2.4 rad s$^{-1}$, Re=2000, laminar model), see Papáček et al. (2017).

### 2.3 Case study: Flashing light enhancement due to hydrodynamically induced light/dark cycles (Taylor vortex flow)

The validation of our just proposed distributed parameter model of microalgae growth (1) was made on our laboratory CTBR, see Fig. 1. CTBR performance was simulated in different flow regimes, resulting in so-called flashing light enhancement, cf. Fig. 3 in Papáček et al. (2017).

## 3 CONCLUSION

We proposed a model of microalgae growth consisting of three interconnected parts: (i) Convection-Reaction-Dispersion PDE, (ii) fluid-dynamic model (a CFD code), and (iii) model of irradiance distribution.

In the case study, we have shown that a simple PSF model well behaves under light-dark cycles hydrodynamically induced in the Couette-Taylor reactor and copes with the requirement imposed on the reaction model, i.e., it correctly describes both the steady-state (photoinhibition - substrate inhibition kinetics) and dynamic phenomena (flashing light effect).

Ongoing modeling efforts will continue in order to develop even more reliable model, e.g., considering the effect of hydrodynamical shear stress on microalgae growth.

## Acknowledgement

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