COMPUTATIONAL FLUID DYNAMICS AS A TOOL TO DESCRIBE BIOFOULING IN BIOREACTORS

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INTRODUCTION

Microalgae cell adhesion, biofouling, plays a critical role in biomass production yield of microalgae cultures. It depends on several factors[1]. During a culture in a photobioreactor (PBR), microalgae cells in the proximity of the PBR wall are subjected to a number of low-range forces. The extended Derjaguin, Landau, Verwey, Overbeek model (XDLVO) stablishes a balance of those forces and predict the cell attachment to solid surfaces[2]. Computer Fluid Dynamics Simulations (CFD) is a powerful tool that allows designing and describing flow behavior in different equipment used in bioprocesses[3]. The XDLVO model can be implemented in CFD Simulations (CFD) to predict cell adhesion in PBRs and help in the design and optimization of culture devices.

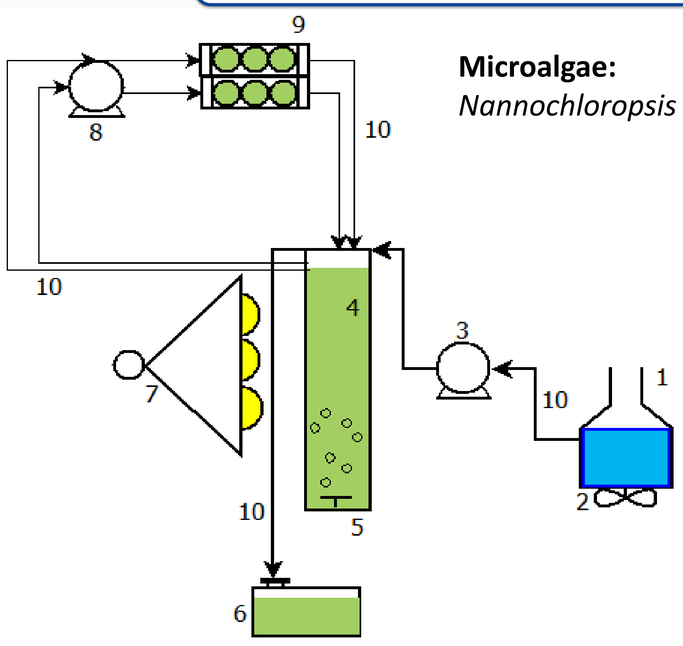
OBJECTIVES

In this study, the following objectives are considered:

- To implement the XDLVO model in CFD simulations;
- To experimentally determine cell adhesion in a simple flow chamber;
- To compare qualitatively the experimental and simulated cell adhesion results.

MATERIALS & METHODS

EXPERIMENTAL SETUP



Microalgae:
Nannochloropsis gaditana

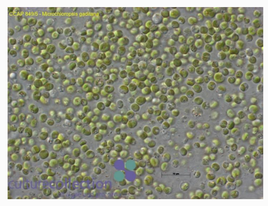


Fig 1. Flowsheet of the experimental setup. (1) Culture medium reservoir; (2) Magnetic mixer; (3) Peristaltic feed pump; (4) 13-L Flat Panel PBR; (5) Sparger; (6) Harvesting tank; (7) Illumination system; (8) Multichannel peristaltic pump; (9) 3-coupon flow chamber with methyl-methacrylate coupons; (10) Silicone tubes.

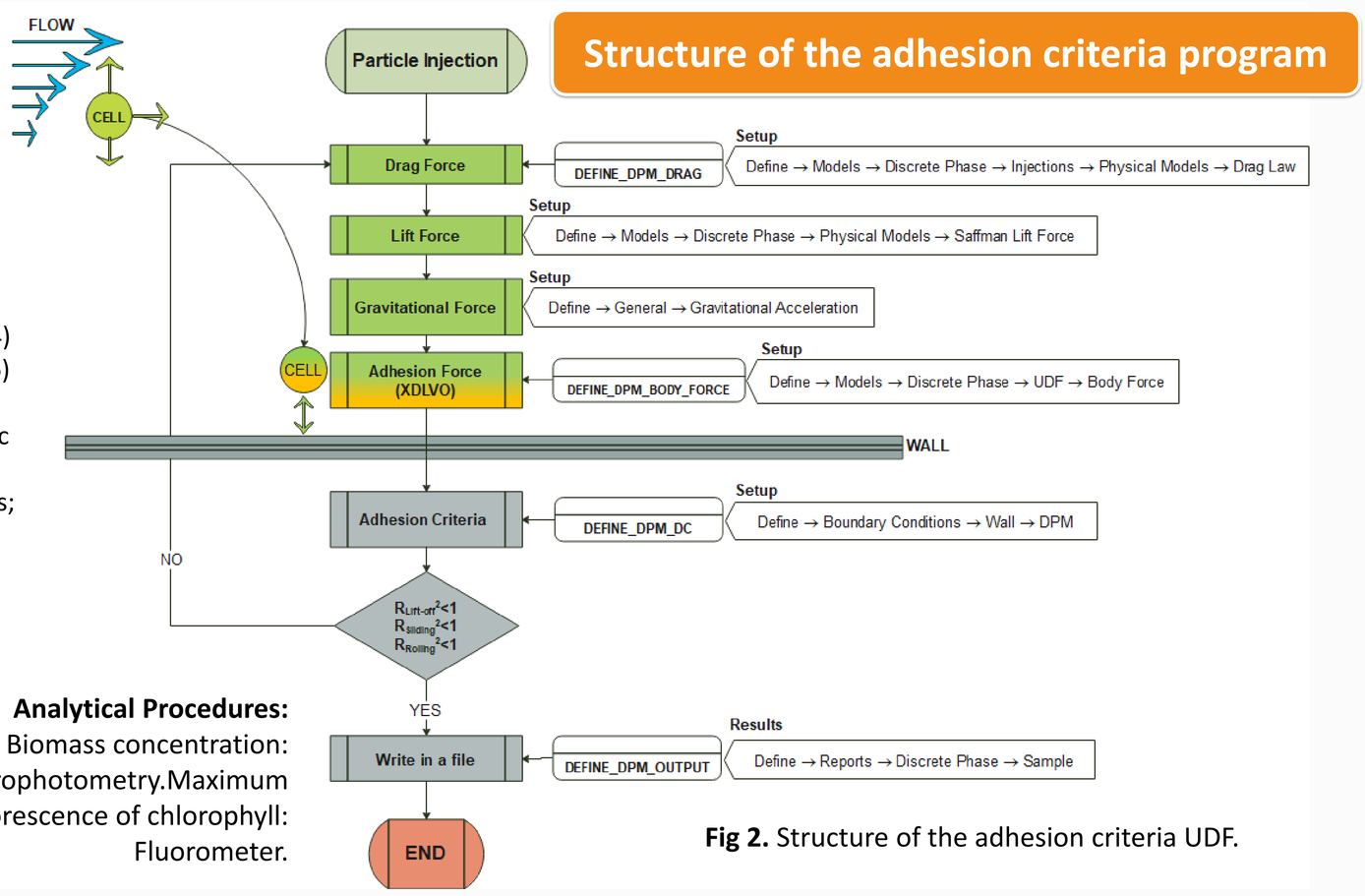
The PBR was run in continuous mode at a dilution rate of 0.1 day^{-1}. The multichannel peristaltic pump fed the flow chamber at a flow rate of 0.3 $mL \cdot min^{-1}$ with the cells suspension from the PBR. The microalgal adhesion intensity on the different coupons was evaluated by measuring the Chlorophyll *a* (*Chla*) fluorescence intensity[4].

Analytical Procedures:
Biomass concentration: spectrophotometry.Maximum fluorescence of chlorophyll: Fluorometer.

Geometry , Mesh and Simulation Parameters

The simulations were performed with Ansys Fluent® v2020 R1 in transient mode.
The polyhedral Mesh consisted of $5.3 \cdot 10^6$ elements. To accuratelly describe flow inside the Flow cell and, specially, close to the coupons an inflation layer was implemented. The first layer thickness was $2 \cdot 10^{-6}$ m. The k-ω turbulence model was used with low Re correction. Individual cell movement was tracked with a Lagrangian frame of reference (DPM) formulation and the adhesion criteria were included in user-defined functions (UDFs)[5] (Fig. 2). Cells were simulated as 4 µm-diameter inert particles with a density of 1200 $kg \cdot m^{-3}$.

CFD SIMULATION



Structure of the adhesion criteria program

Fig 2. Structure of the adhesion criteria UDF.

RESULTS & DISCUSSION

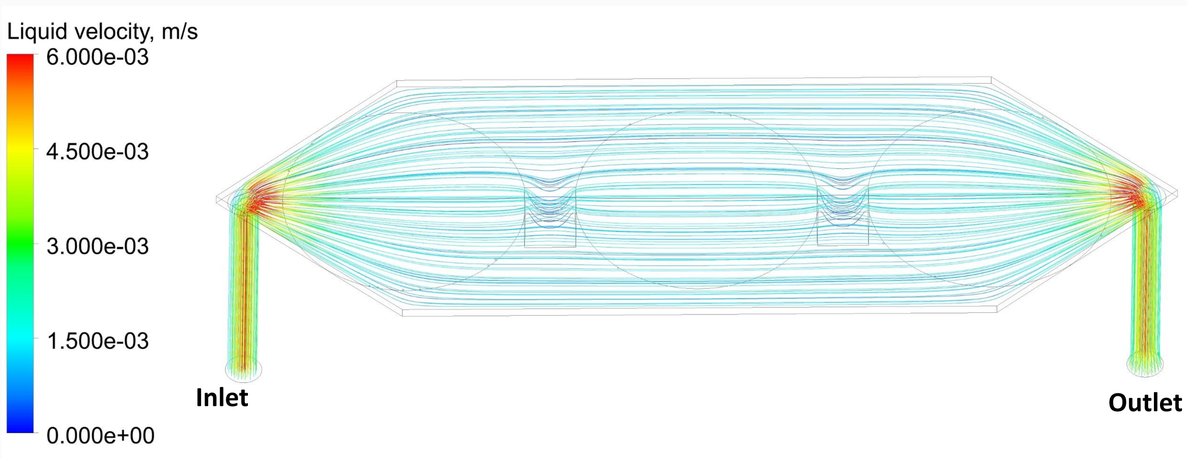


Fig 3. Stream lines of the liquid coloured by velocity magnitude.

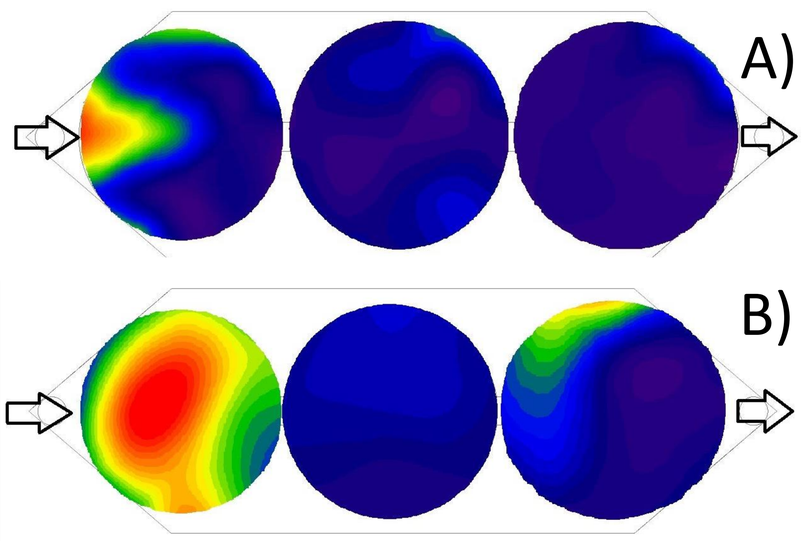


Fig 4. Relative concentration of attached cells on the coupons for experimental device (A) and CFD simulation (B).

In Figure 3, Streamlines that indicate the flow pattern in the microfluidic cell have been plotted in color range according to the liquid velocity. As can be seen, the flow lines form layers which confirms the hypothesis of laminar flow in the device. Inlet and outlet zones, due to the narrowing, provoked an increase in the velocity of around 400%. The observed laminar flow would imply that only the cells that travel through the device enoughly close to the coupon surface would be subjected to sufficient force to be adhered. Since there are not zones of less velocity than the average velocity (around 1.5 10^{-3} m/s), an homogeneous adhesion pattern would be expected. In Figure 4, this patter has been represented for the experimental setup with *N. gaditana* (A) and for the CFD simulation. To do so, cell concentration was measured in the coupons using Chla fluorescence intensity and then relativized. For the simulation, a register of adhered inert particles was used to created the contour plot. Comparing the contours in the first (from left to right) coupon, it can be observed that the relative concentration predicted by the simulation was much higher than the experimental results. On the other hand, the second and third coupon were more correctly simulated (except for a small area on the top of the simulated coupon). In the CFD the number of adhered particles depends on the total number of particles that pass close enough to the surface. Since there much fewer particles than cells, it is expected that the number of adhered cells be lower than the adhered particles (10^7 vs 10^2). Although relativization should avoid this difference, it is possible that more inert particles should be used in the simulation.

CONCLUSIONS

Although our results are preliminary and the model should be improved and validated experimentally, we have demonstrated that the XDVLO model can be implemented in CFD software. For reliable results, a higher number of DPM particles and, probably, more simulation time should be used. Notwithstanding, coupled CFD-DPM can be used as a tool to address the challenge of predicting the microalgae adhesion pattern in PBRs since both fluid dynamics and material surface properties can be simulated.

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