Design of a photobioreactor stirred by a fractal oscillating grid – Mixing time determination by a PLIF method.

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The intensification of mass, momentum or energy transfers is often the keystone for the enhancement of chemical and biochemical processes. In the case of a process involving micro-organisms culture, one should take into account that this intensification does not induce excessive shear stress increase leading to the inhibition of themicro-organism growth and to the decline of the biochemical process performances.

The key player for the culture of the microalgae – photosynthetic micro-organisms used for CO_2 capture or interest molecules production (lipids for biodiesel production, proteins, pigments, carbohydrates, … for therapeutic, food or cosmetic purpose) – is the photobioreactor (PBR) and must promote the nutrients, the gas (CO_2-enriched air bubbles) and the light transfers through the culture medium while ensuring the microalgae viability and growth by limiting the inhibition factor, shear stresses among others. Classical photobioreactors need to compromise between intense mixing and high shear stress on the microalgae: open systems such as open ponds are weakly stirred by paddle wheels (inducing weak shear stresses) but are easy to build and operate while stirred tanks PBRs bring a good mixing but also intense shear stresses in the vicinity of the rotating stirrer ; tubular PBR (in which the circulation of the culture medium is often ensured by a centrifugal pump), bubbles column and airlift PBR (the stirring of the culture medium is ensured by the bubbling itself) offer intermediate compromises (Singh and Sharma, 2012; Fu *et al.*, 2019).

The aim of this work is to design a photobioreactor stirred by an oscillating grid, a stirring device classically used in fluid mechanics experiments to generate nearly isotropic and mean-shear-free turbulence. This kind of stirring device was firstly used to study interfacial and stratified flow and particle sedimentation and flotation. The properties of the flow and turbulence generated by such a stirring system can be monitored by the oscillation and grid parameters: the oscillation amplitude and frequency, and the geometry of the grid (mesh size, bar shape, design of the bar edges, …) (Yan *et al.*, 2007). The geometries of the grids used are intended to be fractal (iterative repetition of base patterns over several length scale). Indeed, fractal fixed grids have been used to study the nearly shear-free and decaying turbulence they generate downstream in wind or water tunnels, and it was found that they allowed for better scale separation in the produced turbulence and better homogeneity and isotropy, compared to their regular counterpart. Therefore, fractal oscillating grids are expected to be of interest for the culture of shear-sensitive microalgae. In addition, as far as we know, fractal oscillating grid flows have never been studied in the past. Different fractal grid pattern (figure 1) will thus be compared: a fractal square pattern, two fractal “I” patterns and a fractal cross-barred grid ; a simple and classical cross-barred grid will be used too as reference (Hurst and Vassilicos, 2007).

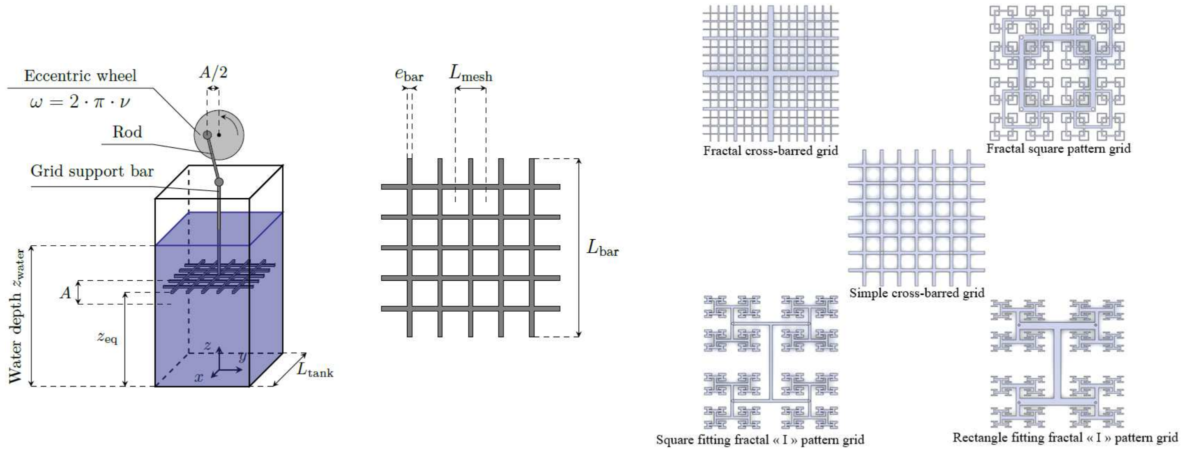

Figure 1. Simplest oscillating grid system (on the left) and grid designs used (on the right).

The first part of our project is to characterise the flow and turbulence properties generated by fractal oscillating grids according as a function of the oscillation and grid parameters. At the end of this first stage, we should be able to say which combination of grid pattern, oscillation amplitude and oscillation frequency appears the best a priori to perform microalgae cultures. The first performed experiments aimed to determine the evolution of the mixing time according to the oscillation and grid parameters. This kind of experiments were carried out by a Planar Laser Induced Fluorescence (PLIF) method: the studied fluid medium is illuminated by a laser sheet and the dispersion of a fluorescent dye (absorbing laser radiation and emitting fluorescence radiation) – rhodamine 6G in our case - is recorded with an sCMOS camera (Jardón-Pérez *et al.*, 2019). While the range of concentrations was too wide to perform an accurate Intensity-concentration calibration (a hook effect appeared in some fluid medium regions due to Beer-Lambert absorption), monitoring of local normalised fluorescence intensities allowed to overcome the inhomogeneity of the laser sheet illumination and obtain meaningful mixing time indicators. This PLIF method also offers the possibility to visualise turbulent scalar structures and measure their scales, and this will be exploited in the next stages of the project. Further Particle Imaging Velocimetry (PIV) measurement will confirm these turbulence length scales estimations (Lacassagne *et al.*, 2019).

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