IMPROVEMENT OF VERTICAL MIXING IN RACEWAY PHOTOBIOREACTOR

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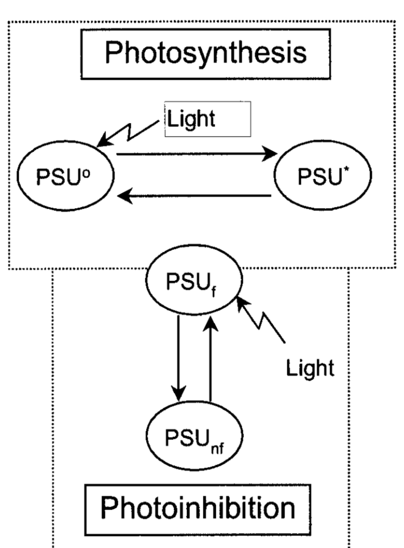
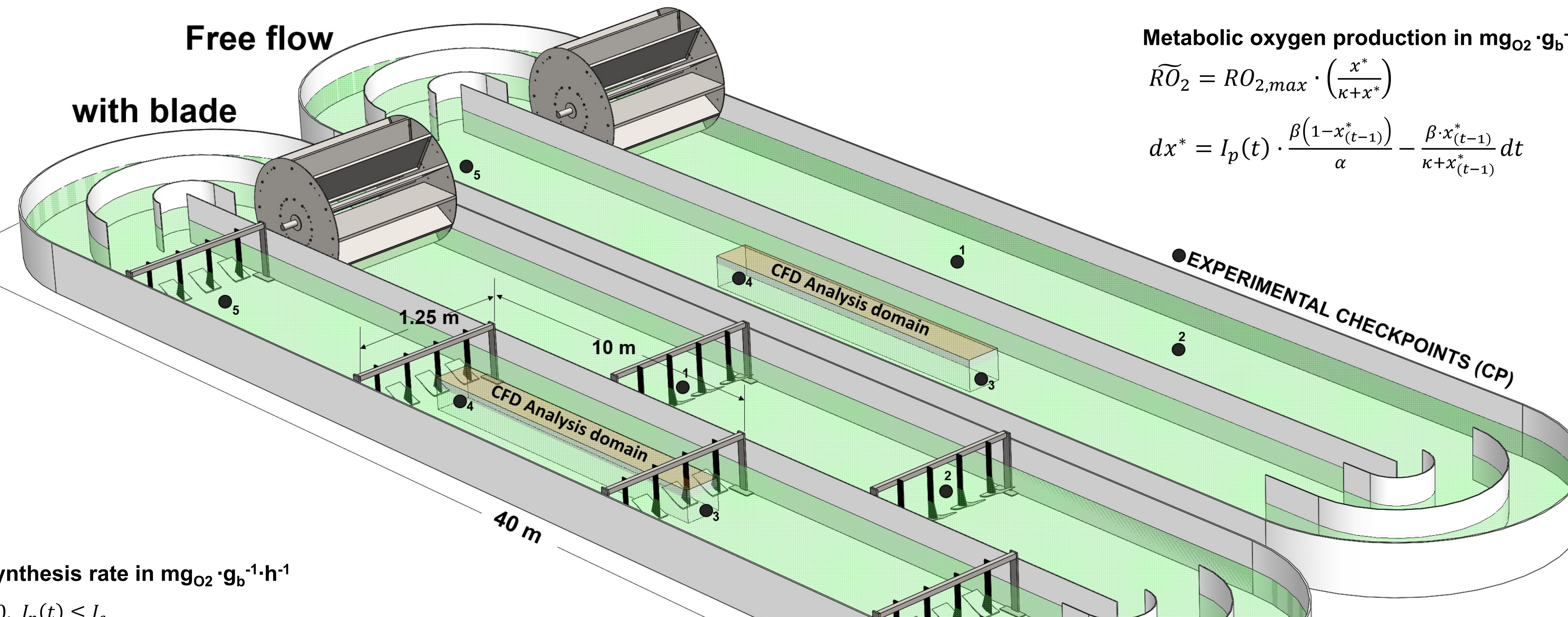
INTRODUCTION

The lack of adequate vertical mixing is one of the factors limiting the productivity of open raceway microalgae reactors. Thus, the existence of large gradients of light and the lack of vertical mixing involve the cells being mainly adapted to local irradiance instead of average irradiance. The adaptation to average irradiance allows maximizing the light utilization efficiency and then maximizing the biomass productivity of microalgae cultures. To overpass this problem different alternatives have been proposed, one of the more suitable being the utilization of blades to improve the vertical mixing. In this work, experimental studies were performed installing blades. The goal is to improve the photosynthetic efficiency, but also a better understanding of the light regime to which the microalgae cells are exposed in these systems and how to improve it.

Computational fluid dynamics (CFD) was used to optimize the design of blades. Moreover, a dynamic photosynthesis model (Rubio Camacho et al., 2003) was used to estimate the photosynthesis rate as a function of the light regime to which the cells are exposed, including photoadaptation and photo-inhibition phenomena. The combination of both tools allows for optimisation of the configuration of the system.



METHOD



Metabolic oxygen production in $mg_{O_2}\cdot g_b^{-1}\cdot h^{-1}$

$$\widetilde{RO}_2 = RO_{2,max}\cdot\left(\frac{x^*}{\kappa+x^*}\right)$$

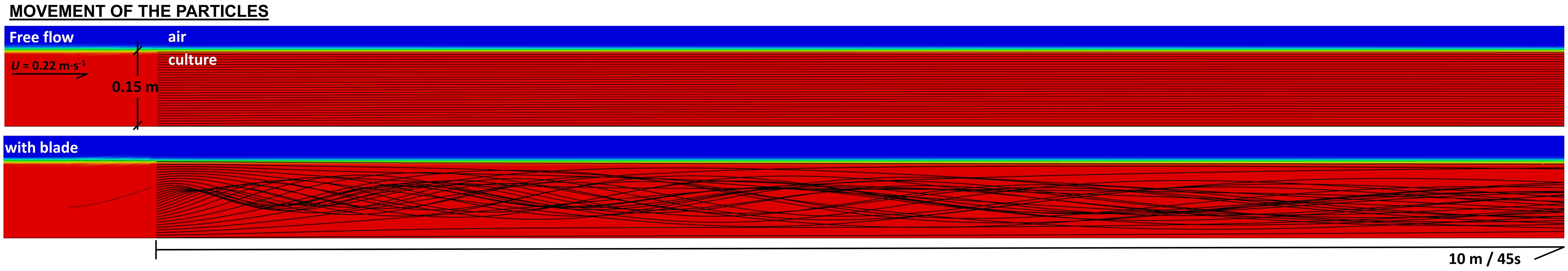
$$dx^* = I_p(t)\cdot\frac{\beta\left(1-x^*_{(t-1)}\right)}{\alpha} - \frac{\beta\cdot x^*_{(t-1)}}{\kappa+x^*_{(t-1)}}dt$$

Photosynthesis rate in $mg_{O_2}\cdot g_b^{-1}\cdot h^{-1}$

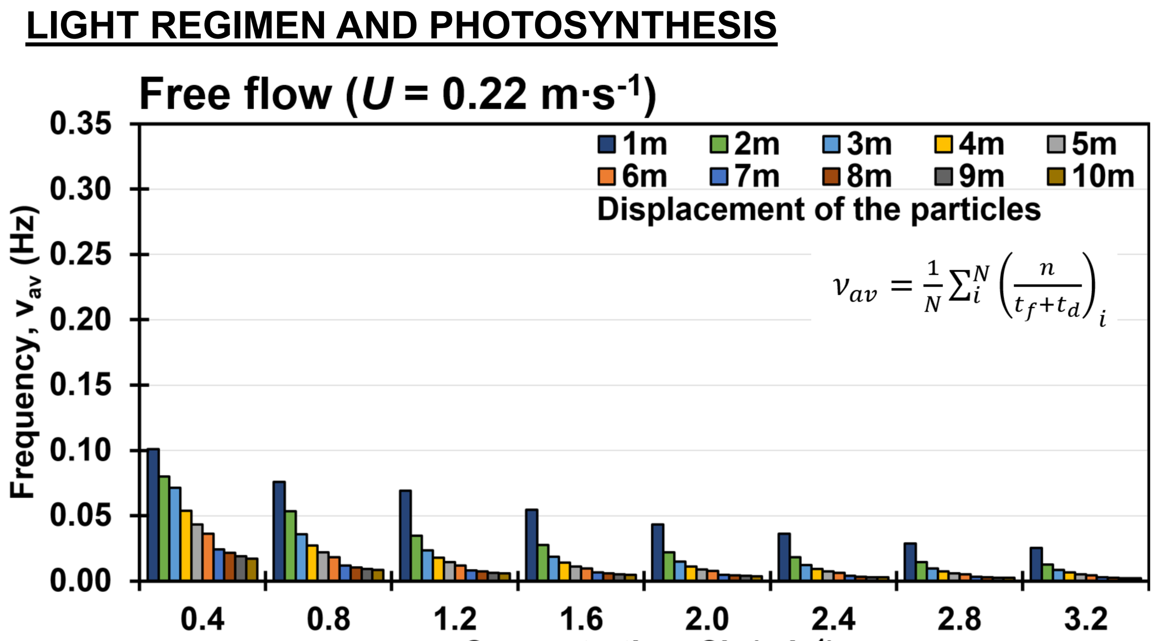
$$RO_2 = \begin{cases} 0, & I_p(t)\le I_c \\ \frac{RO_{2,max}\cdot I_p(t)}{2\alpha}\left(1+\kappa+\frac{\alpha}{I_p(t)}-\sqrt{\left(1-\kappa-\frac{\alpha}{I_p(t)}\right)^2+4\kappa}\right), & KI < I_p(t) > I_c \\ \frac{RO_{2,max}\cdot I_p(t)}{2\alpha}\left(1+\kappa+\frac{\alpha}{I_p(t)}-\sqrt{\left(1-\kappa-\frac{\alpha}{I_p(t)}\right)^2+4\kappa}\right)\left(\frac{1}{1+\delta\sqrt{I_p(t)}}\right), & I_p(t)\ge KI \end{cases}$$

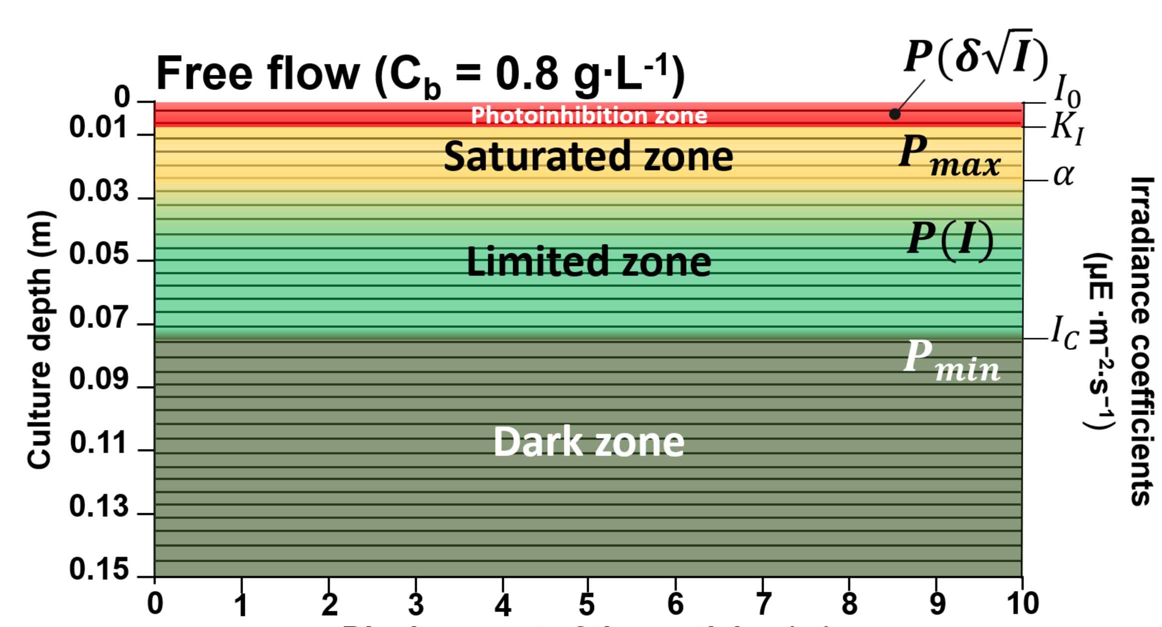
RESULT

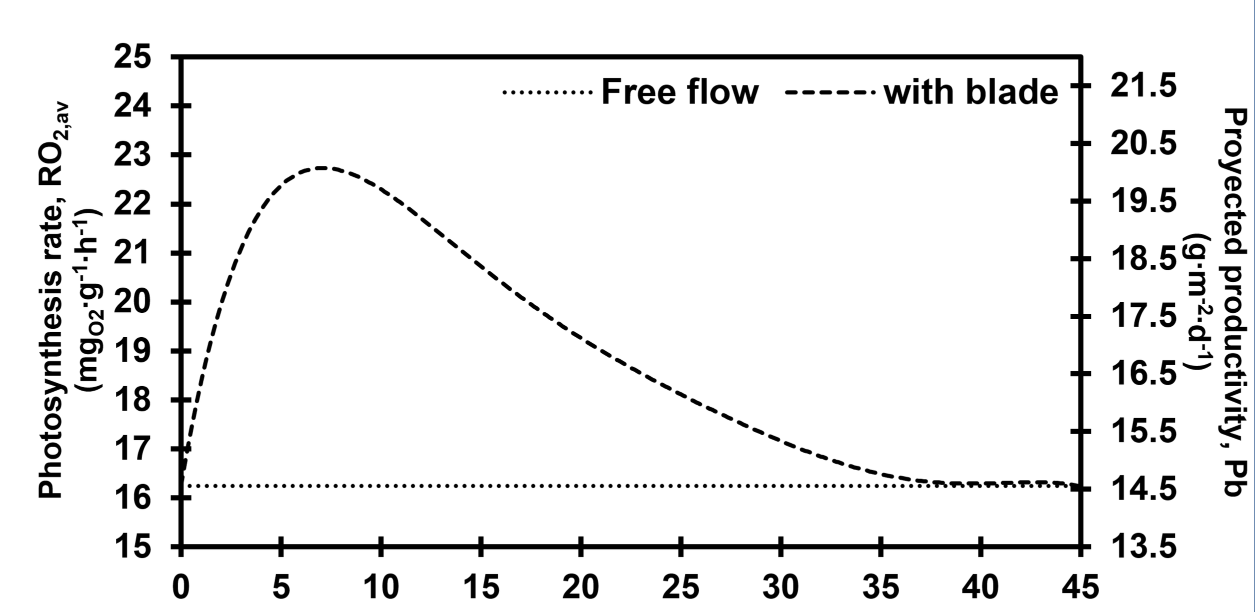
MOVEMENT OF THE PARTICLES

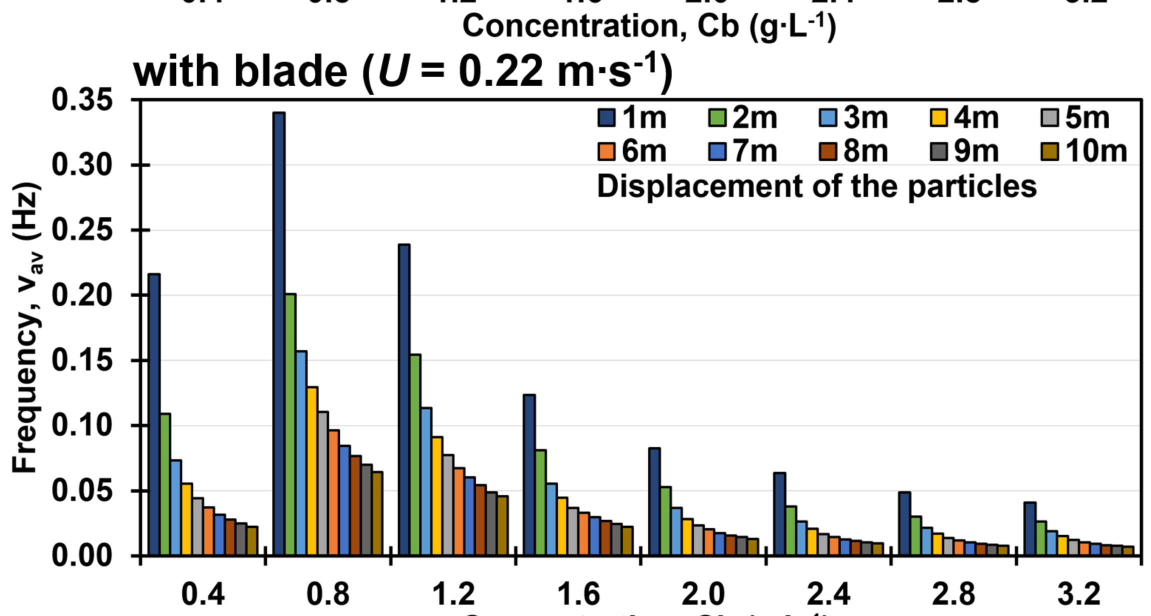


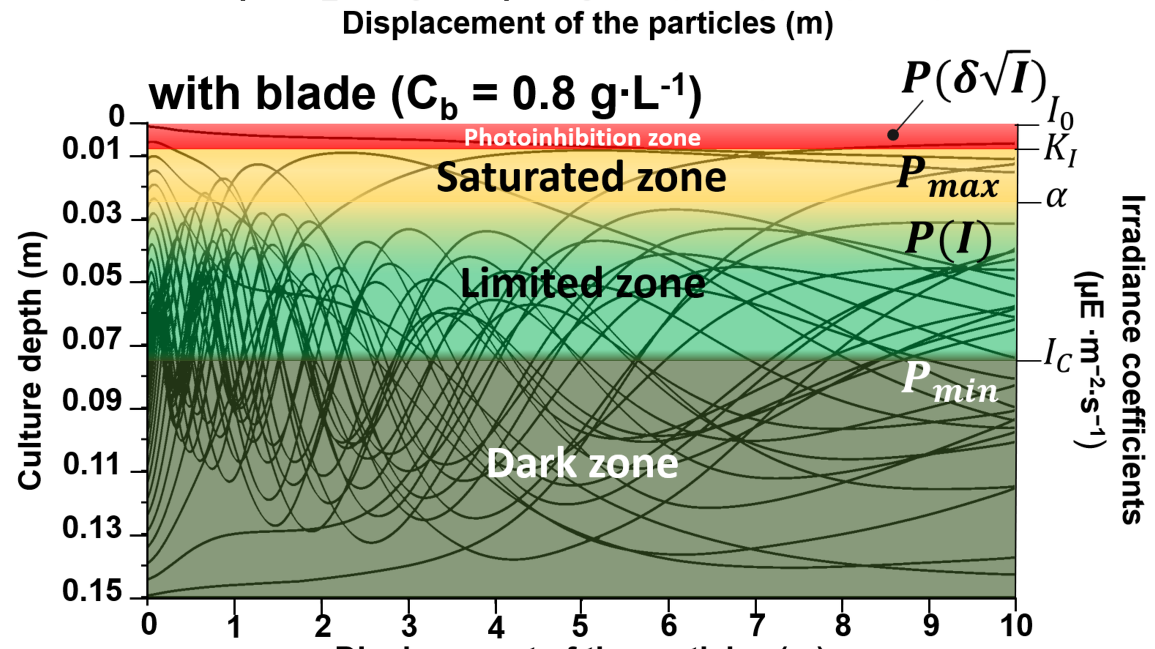
LIGHT REGIMEN AND PHOTOSYNTHESIS

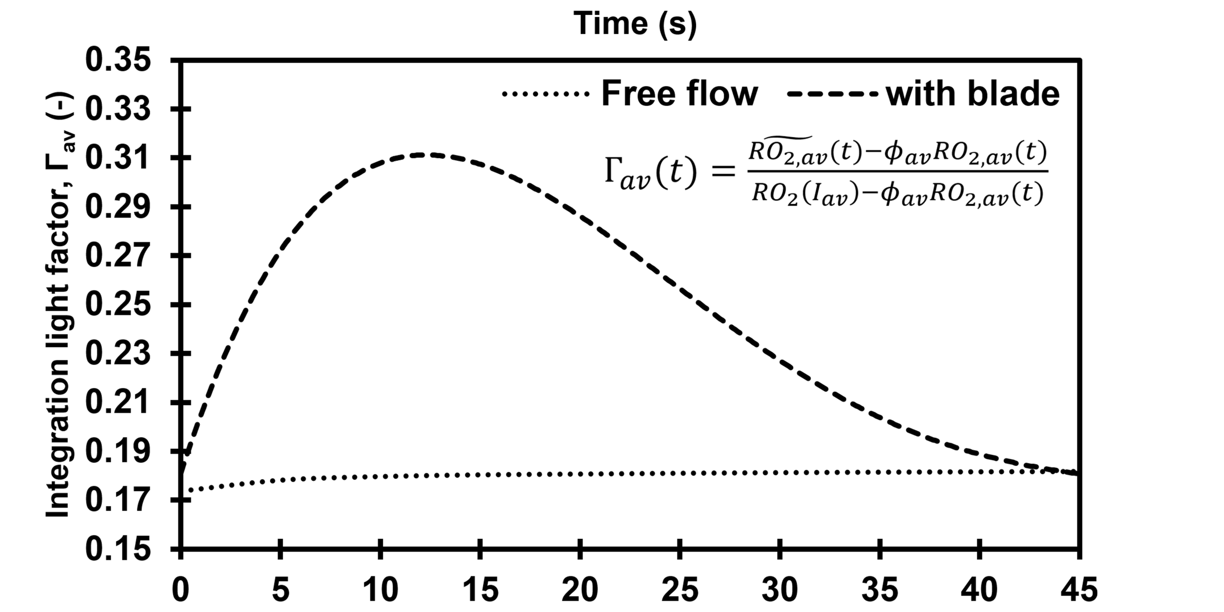


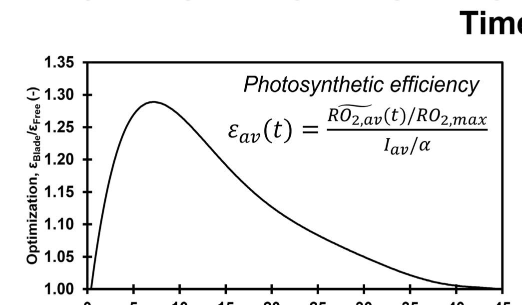


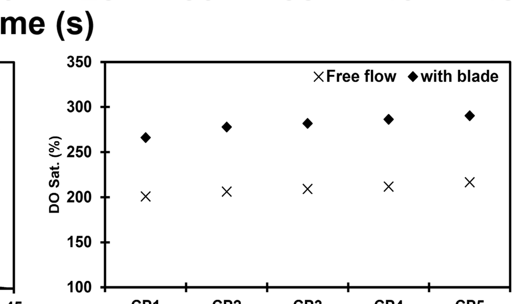












NOMENCLATURE

- I_0 is the incident irradiance in $\mu E\cdot m^{-2}\cdot s^{-1}$
- KI is photoinhibition coefficient in $\mu E\cdot m^{-2}\cdot s^{-1}$
- α is saturation coefficient in $\mu E\cdot m^{-2}\cdot s^{-1}$
- I_c is the compensation irradiance in $\mu E\cdot m^{-2}\cdot s^{-1}$
- I and I_p is the local irradiance in $\mu E\cdot m^{-2}\cdot s^{-1}$
- δ is the photoinhibition parameter in $\mu E\cdot m^{-0.5}\cdot s^{-0.5}$
- I_{av} is the average irradiance in $\mu E\cdot m^{-2}\cdot s^{-1}$
- ν the frequency of L/D cycles in Hz
- ϕ is the illuminated fraction or duty cycle
- t_f and t_d is the time of light and darkness in s
- N is the number of particles
- n is the number of cycles L/D
- P is the the production
- x^* is the fraction of photosynthetic units (PSUs)
- β is the characteristic frequency of the strain in Hz
- κ is the form factor of the dynamic model

CONCLUSION

The vertical mixing generated by the blades begins to be dissipated after 5 m, but the photosynthetic benefits are observed including can be observed a greater distance. The frequency of exposition improves three times concerning conventional systems which allows an increase in photosynthesis rate and productivity up to 30% higher, light integration is 36% higher using blades, optimization has been 27% higher comparatively, and experimentally oxygen saturation has been 30% higher. These results confirm the benefits of optimizing the mixing in microalgae cultures, especially focusing on the movement of the cells between the different illuminated zones. Additional work is underway to increase the photosynthesis rate and final biomass productivity, it is expected to increase the microalgae production capacity of actual photobioreactors up to 50%, regardless of location, maintaining low energy consumption and CAPEX.

REFERENCE

Rubio Camacho, F., García Camacho, F., Fernández Sevilla, J.M., Chisti, Y., Molina Grima, E., 2003. A mechanistic model of photosynthesis in microalgae. Biotechnol. Bioeng. 81, 459–473. https://doi.org/10.1002/bit.10492

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