# Photobioreactor Simulation for Microalgae Chlorella Cultivation in Process

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**Abstract.** Three-dimensional simulation of light fields in the photobioreactor for Chlorella cultivation was performed. It was shown, that light flux reduced due to the increase of optical density and growth of microalgae cells concentration. According to the fact that light intensity is an important factor, affecting growth rate and development of microalgae cells, process automation and light flux increase in dependence to Chlorella cells gain are needed to be introduced [1-3].

## 1. Introduction

As the microbiology has developed to the industrial level, lot of data has been cumulated, allowing use of additional intense lighting for microalgae cultivation. At the start of microalgae operations, the influence of light flux on Chlorella investigations were conducted. The dose-effect, the relation between the consumed by the object light dose and the level of cultivation, was the result. Following that, two logically defined solutions were created – orienting cells uniformly against the light source or raising light intensity of the irradiation source.

The problems have become far more challenging with the transition to industrial and semi-industrial levels of desired products derivation in light-dependent technical process. It is complicated to expose microalgae suspension to radiation equally in large volume reservoirs and at the same time avoid photoinhibition of the cells in close proximity to the light source. This implies that radiance sources should be strictly specified and located to maximally expose the entire volume of the suspension and remain energy-efficient.

## 2. Materials and Methods

Information gain about the characteristics of existing bioreactor models was accomplished before starting simulation. The desired light intensity for microalgae should be at the average rate of 14 klx [4, 5].

The photobioreactor simulation consists of components with properties as following:

1.   Solid-state light source (100 pcs) – light-emitting diode XLamp XT-E White. Radiators are placed separately at the distance of 44 mm (from one exposed edge to another). Overall dimensions 3.45×3.45 mm [6].

2.   The reservoir is a cylindrical glass tank. Reservoir if 68 cm in height, 20 cm in diameter. Glass properties: Rho = 6%; transmission capacity = 70%; undulation = 0%; reflection effect = 90%.

3.   Top cover. Conjectured material for construction – polystyrene: Rho = 90%; transmission capacity = 0%; undulation = 60%; reflection effect = 20%.

4.　Reflector. Material – tinfoil, properties set in accordance with measurements: Rho = 80%; transmission capacity = 0%; undulation = 0%; reflection effect = 80%.

5.　Suspension simulation, which fills the reservoir to the height of 50 cm, has following properties:

•　Properties of the medium at the beginning of cultivation process. Suspension imitation with transmission capacity = 80% was added to the simulation with optical density 0.098 of the initial rate.

•　Properties of the medium at the end of cultivation process. Suspension imitation with transmission capacity = 58% was added to the simulation with optical density 0.233 of the initial rate.

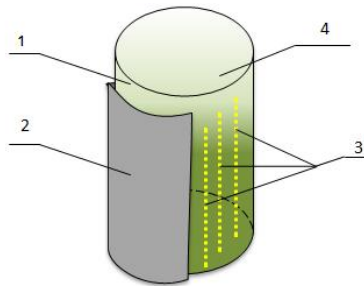General configuration of the simulation is depicted in the figure 1.



**Figure 1.** Photobioreactor simulation: 1–reservoir; 2–reflector; 3–LED lines; 4–top cover.

Three-dimensional simulation of the cultivation process was conducted in software application Dialux [7].

Dialux enables to take into consideration colour, reflection index and surface texture during lighting calculation. As a result of data processing complete general 3D elevation of the reservoir and graphics image of light distribution on the surface could be obtained. The software also allows viewing the light intensity distribution with help of fictitious colour.

In present work the simulation, which represented two stages of cultivation, was created. The two stages were: initial–when microalgae concentration was low; final–after 12 hours when the cultivation was over and Chlorella concentration has risen. Simulation without suspension have been created as well.

The final step was to calculate the lost factor while analyzing the results of two stages simulations not including medium agitation.

With the use of fictitious colour in Dialux, light intensity distribution on the surface inside the reservoir could be observed. Figure 2a illustrates light distribution at the beginning of the process, figure 2b–after 12 hours of cultivation, figure 2c–without suspension.
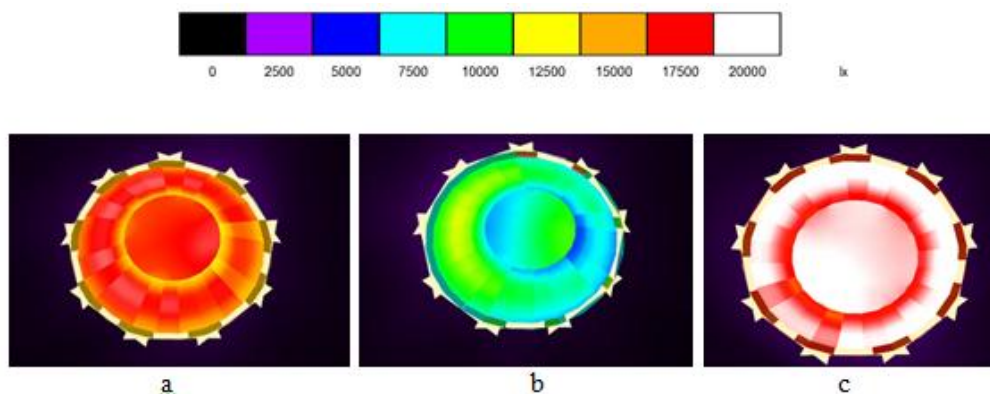


**Figure 2.** Light intensity distribution using fictitious colour (plan view):
a-beginning of the cultivation process; b-after 12 hours; c-without suspension.

Figure 3. shows estimated points in the inline directions of the two cultivation stages.
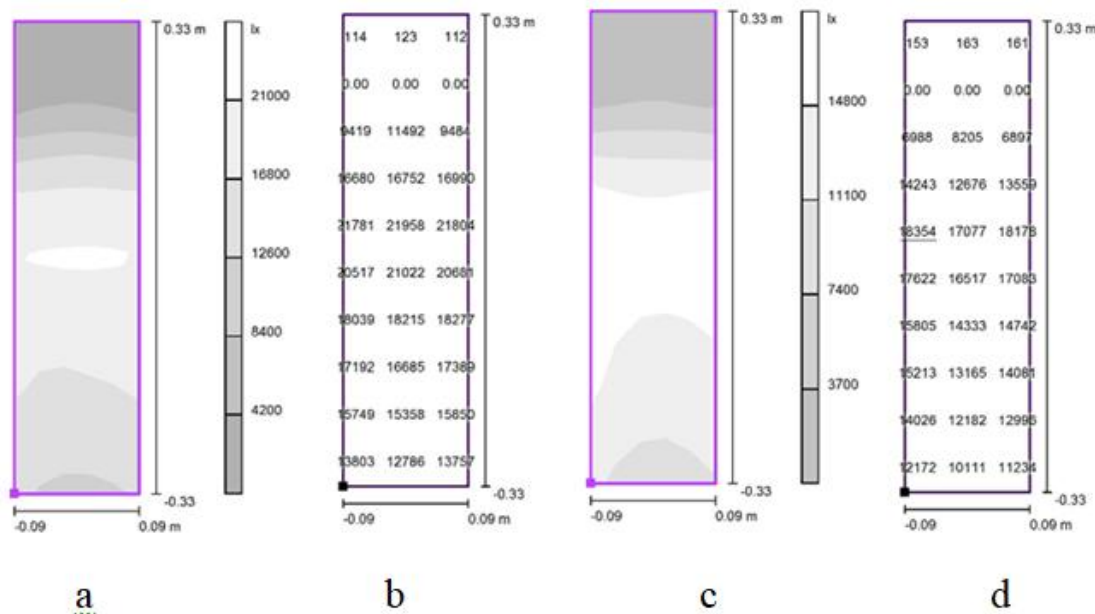


**Figure 3.** Photosynthetic photon flux density (PPFD, μmol/cm$^2$) of luminescent tubes
(Philips, TLD 18 W) at the surface of *C. hybridum* plants *in vitro* cultured:
control group–achromatic (white) light WL, group–WL and red light WL+RL,
group 2–WL and blue light WL+BL, group 3–WL and green light WL+GL.

Lost factor was calculated by using target exposed points, which were located at the same positions
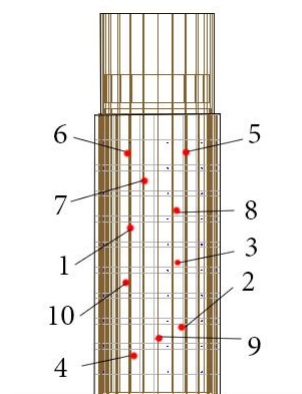for both simulations. Figure 4 depicts estimated points order; the results are arranged at the table 1.



**Figure 4**. Target points placement.

**Table 1.** Values in target points, simulating microalgae suspension,
at the beginning ant the end of cultivation process.

| Target point | Light intensity without suspension (lx) | Light intensity at the beginning ( lx) | Light intensity after 12 hours (lx) | Light intensity reduction after 12 hours (%) |
|---|---|---|---|---|
| **1** | 24338 | 16712 | 8907 | 46,7 |
| **2** | 26024 | 18158 | 12352 | 32,0 |
| **3** | 25813 | 17724 | 8318 | 53,1 |
| **4** | 23645 | 16388 | 3917 | 76,1 |
| **5** | 24491 | 17056 | 14008 | 17,9 |
| **6** | 13108 | 7386 | 4082 | 44,7 |
| **7** | 15476 | 9437 | 3871 | 59,0 |
| **8** | 23610 | 16024 | 8043 | 49,8 |
| **9** | 24916 | 17126 | 9453 | 44,8 |
| **10** | 28859 | 20120 | 4661 | 76,8 |

## 3. Results

The simulation showed the decrease of light flux by an average 50.1% after 12 hours of microalgae cultivation in comparison to initial characteristics. The cause of this result is microalgae Chlorella cells growth. Thus concentration rate raises and transmittance of the suspension reduces. This means the necessity of lighting adjustment, light flux augmentation throughout the microalgae cultivation particularly. By applying fully-automated light control system desired light intensity distribution in the reservoir could be maintained and energy efficiency of the photobioreactor could be increased.

## 4. Conclusion

Nowadays, microalgae are widely used in various spheres: agriculture, food industry, medicine and esthetics, as wastewater treatment, oxygen and biofuel manufacturing. However, cultivation of light-dependent microorganisms is associated with high energy cost for lighting. Applying LED light sources with appropriate spectrum for maximum microalgae cells gain and revealing the relation between light intensity and optical density of microalgae suspension could significantly reduce energy consumption of industrial photobioreactors.

## Acknowledgments

## References

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