Proc. KMB Autumn Meeting
October 26, 2002, Seoul, Korea

Optimal Design and Operating Method of a Photobioreactor with Respect to Light Energy Input

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Abstract

Photosynthesis is the most abundant energy-storing and life-supporting process on earth. Many researchers, especially microalgal biotechnologists, have studied the utilization of the photosynthetic machinery for the production of new bioproducts and possible environmental applications over the last several decades. Despite the importance of light energy for the growth of photosynthetic cells, the characterization and utilization of light energy has been underestimated in the field of photobioreactor engineering. Light energy must be supplied continuously at an appropriate level, and the light energy supplied should be utilized at the highest possible efficiency.

To characterize the irradiance conditions in a photobioreactor, we developed a light distribution model for a single-radiator system and then extended the model to multiple radiators using the concept of parallel translation. Mathematical expressions for the local light intensity and the average light intensity were derived for a cylindrical photobioreactor with multiple internal radiators. This study also proposes a new design of the internally radiating photobioreactor, which combines the advantages of an air-lift bioreactor and an internally radiating system, and an efficient way of supplying light energy into the photobioreactor during cell cultivation. The proposed model was used to predict the irradiance levels inside the photobioreactor using *Synechococcus* sp. PCC 6301 as a model photosynthetic microorganism.

The predicted light intensity values were found to be very close to those obtained experimentally, which suggests that the proposed model is capable of accurately interpreting the local light energy profiles inside the photobioreactor system. The

effects of cell density, radiator number, and radiator position were interpreted through photographic and model simulation studies. The model simulation study was intended to identify the design criteria for the construction of efficient photobioreactors. The simulation results indicate that there exists an optimal position of internal radiators and the position is varied by changing radiator number and cell concentration. Due to the simplicity and flexibility of the proposed model, it was also possible to predict the light conditions in other complex photobioreactors, including optical-fiber and pond-type photobioreactors.

Furthermore, the proposed model was expanded to an externally radiating photobioreactor with appropriate modification of the model equations. Light attenuation phenomena in externally radiating photobioreactors were expressed by using three model parameters, and these empirical parameters were evaluated by following the same procedure for internal radiators. The efficiency of internally and/or externally radiating methods was investigated based on both average light intensity and light distribution profiles. What the present study makes clear is that the quantitative analysis of internally and/or externally radiating methods can be made on the same mathematical background.

The lumostatic approach was also investigated to develop an efficient way of supplying light energy into the photobioreactor during cell cultivation. Since excessive light energy induced photoinhibition at the early growth stage, the strategy of lumostatic operation was developed in order to maintain the light condition at an appropriate level during cell cultivation. In this study, the light condition was regulated successfully by increasing the number of internal radiators. During cell cultivation, the internal radiators can be turned on successively after calculating the average light intensity from the light distribution model. The model-based control of irradiating level enabled us to harvest a larger amount of cells without showing the photoinhibited growth. Other favorable results included the reduction of cultivation time and lower consumption of irradiating power.

The model-based study in this work is a preliminary work on investigating the light transfer phenomena in photobioreactor engineering. This model-based study presented here will offer helpful tools to bioengineers for optimal design and efficient operating method of a photobioreactor. Using this work as a basis, it may now be possible to achieve the same level of refinement on growth kinetics in the photobioreactor by relating the irradiance levels to growth rate of photosynthetic cells.

References

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