BASIC STUDY ON OPTIMIZATION OF RACEWAY-TYPE ALGAL CULTIVATOR

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Introduction

In connection with the issue of global warming by CO₂, we have been examining possible methods for effective use of CO₂ by fixing it by means of biological techniques. Special attention has been paid to microalgae because they are fast in CO₂ fixation and can be industrially mass-cultured in high density.

The production rate of microalgae is influenced by the nutrients, the light intensity and other operation conditions of algal cultivators. In this paper, the results of the experiments and the theoretical analysis of the optimum conditions in a raceway-type algal cultivator are reported.

Fig. 1 Model of raceway-type cultivator

1. Analysis of Raceway-Type Algal Cultivator

1.1 Algal specific values

The photosynthetic production rate of algae defined by O₂ production rate k_P is given as follows (Iwamura, 1987) in which K_P , ϕ and ρ are algal specific values.

$$k_P = K_P \{ I / (I + \phi) - \rho / K_P \} \quad (1)$$

These specific values have been measured for some conventional algae (Matsumoto and Hamasaki, 1992, Tamiya and Iwamura, 1953).

1.2 Analysis

An attempt to estimate the influence of the operation conditions in the raceway-type algal cultivator was made. We consider the analytical model as shown in Fig. 1, in which light is radiated on the upper part of the raceway type cultivator. Here, the following assumptions were made.

- (1) There is no algal cell concentration distribution in the cultivator (Turbulent flow occurs in the general operation conditions)
- (2) The light intensity I in the cultivator is given by the Lambert-Bear law as shown in Eq. (2) in which ε ,

C_A and l are, respectively, absorption coefficient of algal cell, algal cell concentration and optical path length.

$$I = I_0 \exp(-\varepsilon C_A l) \quad (2)$$

In this case, the algal production rate q_A is given as Eq. (3), in which γ is the ratio of specific production rate of algae to that of O₂.

$$q_A = \gamma K_P W L C_A \int_0^H \{ I / (I + \phi) - \rho / K_P \} dx \quad (3)$$

$$= \frac{\gamma K_P W L}{\varepsilon} \left\{ \ln \left(\frac{I_0 + \phi}{I_H + \phi} \right) - \frac{\rho}{K_P} \ln \left(\frac{I_0}{I_H} \right) \right\} \quad (4)$$

$$I_H = I_0 \exp(-\varepsilon C_A H) \quad (5)$$

The condition under which q_A takes the maximum value is expressed by Eq. (6)

$$\partial q_A / \partial C_A = 0 \quad (6)$$

Differentiation of Eq. (4) with C_A gives

$$\partial q_A / \partial C_A = \gamma K_P W L H \{ I_H / (I_H + \phi) - \rho / K_P \} \quad (7)$$

From Eqs. (6) and (7) C_{AM} which makes q_A maximum is given as follows.

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Fig. 2 Test apparatus of algal cultivator

Table 1 Standard medium of f/2 sea water

NaNO ₃	300 mg
NaH ₂ PO ₄ ·H ₂ O	20 mg
Na ₂ SiO ₃ ·9H ₂ O	30 mg
Thiamine-HCl	100 µg
Biotin	0.5 µg
B ₁₂	0.5 µg
Trace elements stock solution	1 ml
Sea water (artificial sea water)	1000 ml

Trace elements stock solution	
Na ₂ EDTA	4.36 g
FeCl ₃ ·6H ₂ O	3.15 mg
MnCl ₂ ·4H ₂ O	180 mg
CuSO ₄ ·5H ₂ O	10 mg
ZnSO ₄ ·7H ₂ O	22 mg
CoCl ₂ ·6H ₂ O	10 mg
Na ₂ MoO ₄ ·2H ₂ O	6 mg
Distilled water	1000 ml

$$C_{AM} = 1/(\epsilon H) \ln(I_0(K_P/\rho - 1)/\phi) \quad (8)$$

$$I_{HM} = \phi/(K_P/\rho - 1) \quad (9)$$

From Eqs. (4) and (9) the maximum value of q_A is given as follows.

$$q_{AM} = \frac{\gamma K_P W L}{\epsilon} \left\{ \ln \left(\frac{I_0 + \phi}{I_{HM} + \phi} \right) - \rho / K_P \ln \left(\frac{I_0}{I_{HM}} \right) \right\} \quad (10)$$

Eq. (10) indicates that the maximum production rate of algae q_{AM} depends the light intensity I_0 , and neither the algal cell concentration C_A nor the depth of the cultivator H influence q_{AM} .

2. Experimental

An algal cultivation test was conducted to confirm the above analytical result.

Nannochloropsis salina was used as an algal strain. The experimental apparatus used for the algal cultivation is shown in Fig. 2. This apparatus consists of an algal cultivator made of hard glass, a

Fig. 3 Algal cultivation test result (algal strain=*nannochloropsis salina*, temperature=25°C)

Table 2 Optimum operation conditions of raceway-type algal cultivator

I_0	10 klx		50 klx	
	H [m]	C_{AM} [mg/l]	C_{AM} [mg/l]	$H \cdot C_{AM}$ [m·mg/l]
0.05		700	35	1000
0.10		350	35	500
0.24		150	35	210

metal halide lamp and a thermostat. 5% CO₂ gas mixed with air was supplied to the cultivator and the temperature of the cultivator was maintained at 25°C. The standard medium of f/2 sea water, as shown Table 1 was used as the medium. The experiment was carried out at various light intensities I_0 and the depths of cultivator H . The production rate of algae was obtained from the time-course of the algal cell concentration.

3. Results

Figure 3 indicates the relation between q_A and C_A with the parameters of I_0 and H . q_A varies with the value of C_A , but the maximum value q_{AM} is a function of I_0 alone, indicating no relation of C_A and H . Where, other conditions such as medium and CO₂ gas concentration were used sufficient conditions as shown in the previous chapter, and these are not limited conditions for cultivation. In Table 2 the conditions which maximize the values of q_A are listed. It is seen that $H C_{AM}$ is constant as supposed by Eq. (8). When I_0 is given, the optimum operation conditions of a raceway-type algal cultivator (H , C_A) can be estimated by this relation.

Nomenclature

C_A	=	algal cell concentration	[kg/m ³]
H	=	depth of algal cultivator	[m]
I	=	light intensity	[lux]
k_P	=	specific production rate of algae	[g/(kg·h)]
K_P	=	constant	[g/(kg·h)]
L	=	length of raceway cultivator	[m]
l	=	optical pass length	[m]
q_A	=	production rate of algae	[g/(m ² ·d)]
W	=	width of raceway cultivator	[m]
γ	=	ratio of specific production rate of algae to that of O ₂	[kg/m ³]
ε	=	absorption coefficient of algal cell	[(kg/m ³) ⁻¹ ·m ⁻¹]
ρ	=	respiratory rate	[g/(kg·h)]
ϕ	=	constant	[lux]

<Subscripts>

O	=	water surface of raceway cultivator
H	=	bottom of raceway cultivator
M	=	maximum

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