Fotobiorreactores para la producción masiva de microalgas

Acién Fernández F.G.; García Camacho F.; Fernández Sevilla J.M. y Molina Grima E.

Objectives

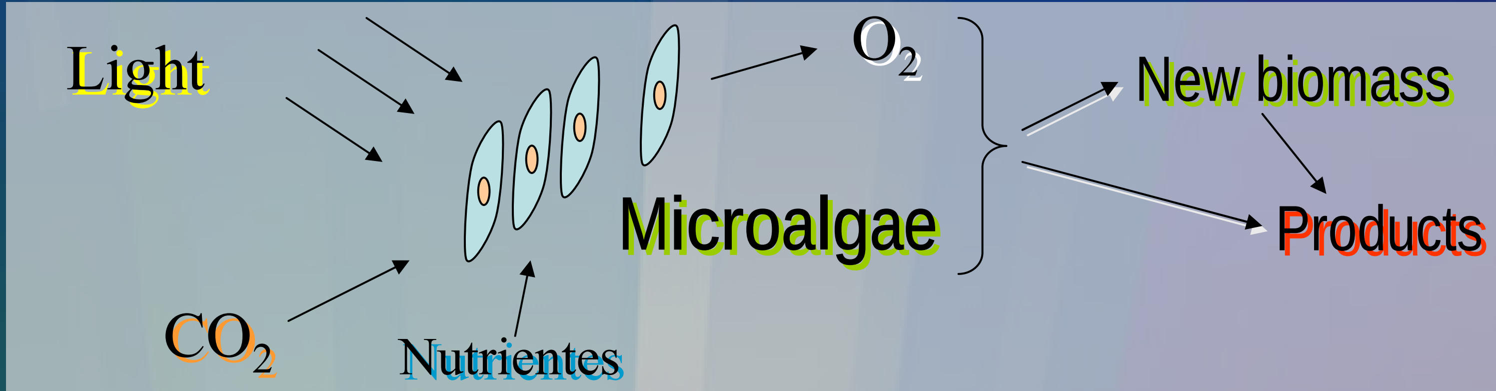
- Reviewing the major types of photobioreactors used for the culture of microalgae.

- Principles of fluid mechanics, gas-liquid mass transfer and irradiance controlled microalgal growth will be integrated into a method for design bubble colums and tubular photobioreactors.

- Scale-up.

Photobioreactor design issues

Light limited growth



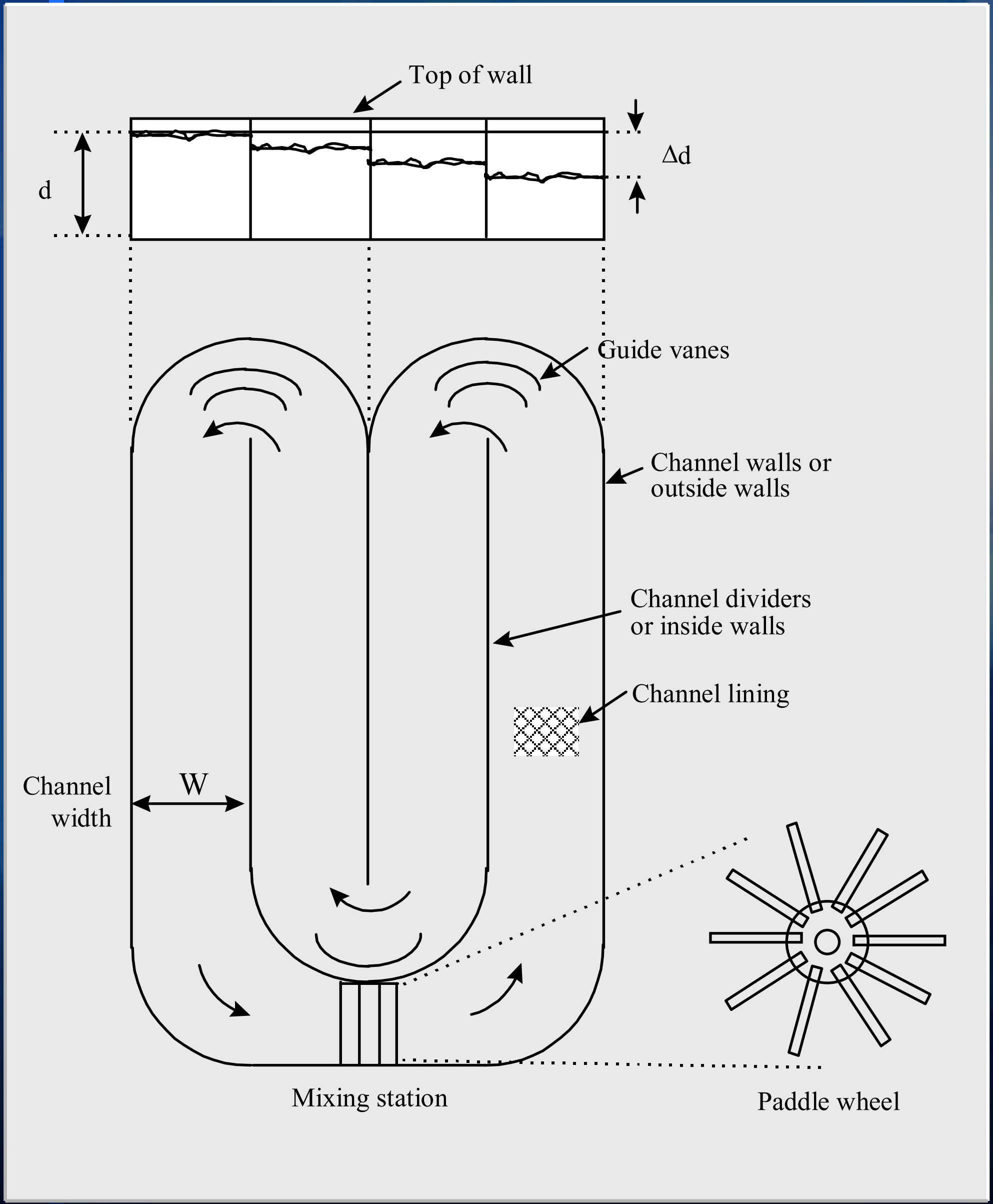
microalgal culture systems

- Supply sufficent light to support high growth rate (μ)
- Support high biomass density (Cb) for
  - High productivity (Pb)
  - Complete light harvesting
- Supply CO_2, remove O_2, mixing

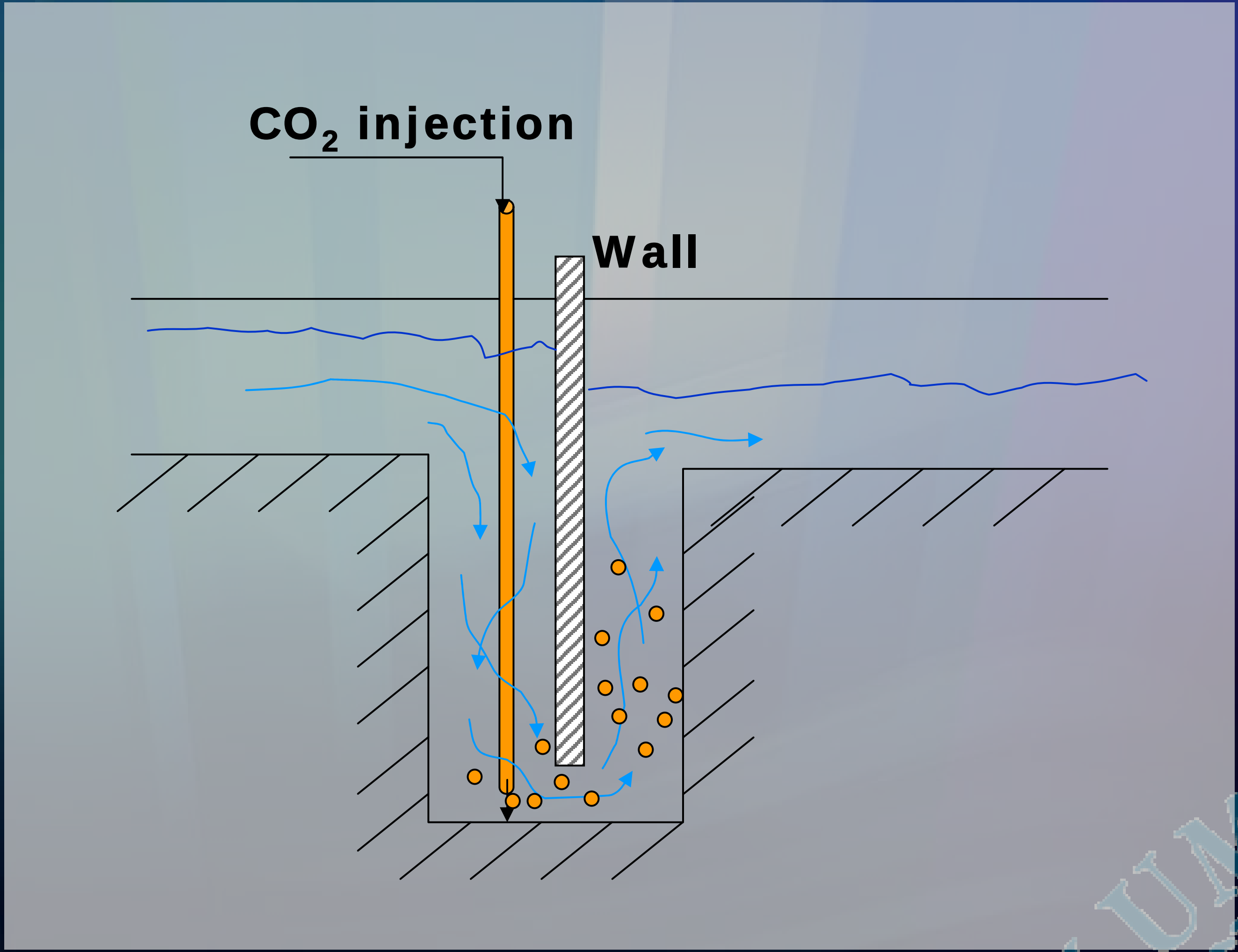
Light limited growth

High productivity → High biomass density → Optically thick cultures → Light supply impeded

Open raceways (1): description



Open raceways (2): CO_2 supply



Open raceways (3): mixing

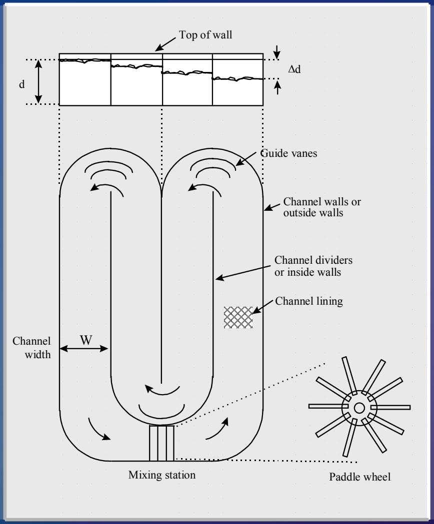
- **Mean channel velocity, v (m s^{-1})**

$$v = \frac{1}{n} R^{2/3} \cdot S^{1/2}$$

n = 0.008 – 0.03, manning friction factor

R = Hydraulic radius

S = Energy loss rate per unit length in the channel



- **Channel length, L (m)**

$$L = \frac{\Delta d\,(dw/(w+2d))^{4/3}}{V^2 \cdot n^2}$$

- **Paddle wheel's power requirements, P (kW)**

$$P = \frac{Q \cdot \rho \cdot \Delta d}{\eta}$$

Open raceways (4): drawbacks

- Contamination and temperature are difficult to control
- The culture depth cannot be reduced below 12 to 15 cm or a severe reduction of flow and turbulence would occur
- Large areal volumes of 120-150 L m^{-2} are usual and therefore low cell concentration is attained (≈500 mg L^{-1})
- Low cell concentration increases the cost of harvesting

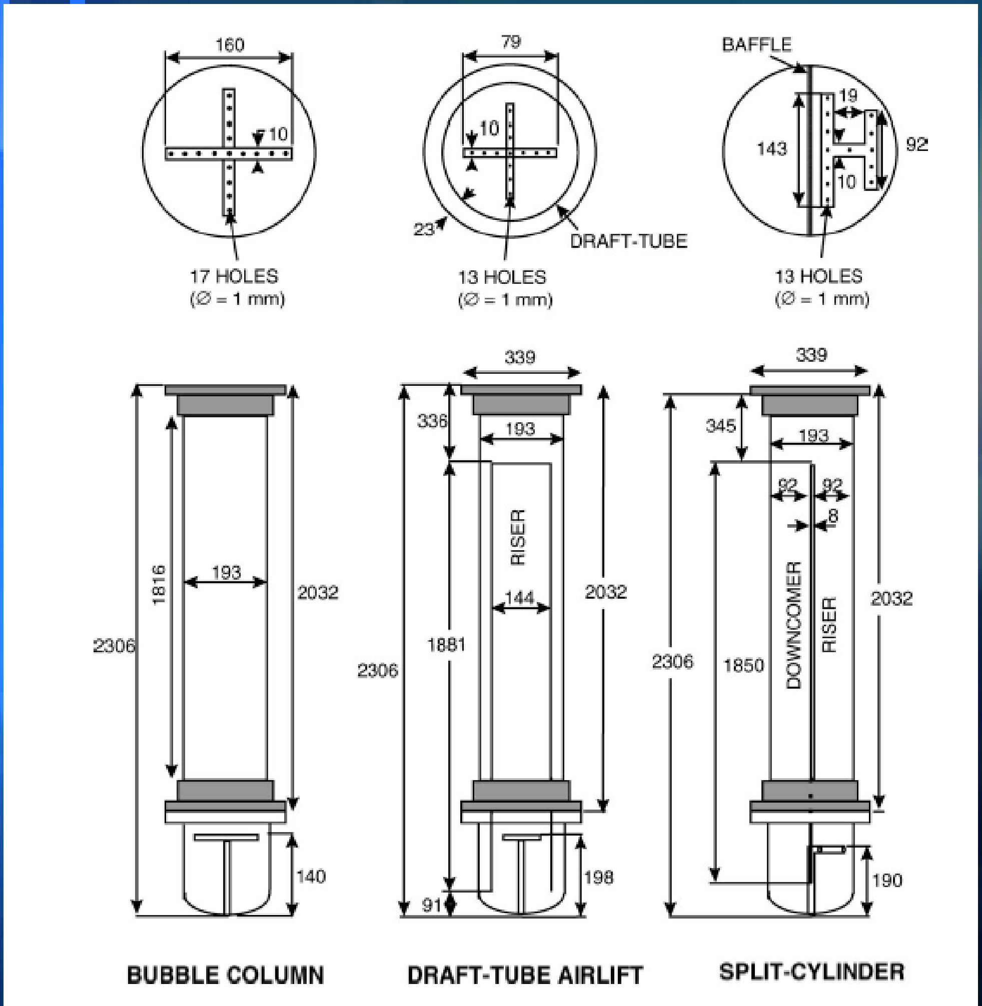
Enclosed photobioreactors

- Tubular

  -Bubble column type
  -Horizontal and fence configuration

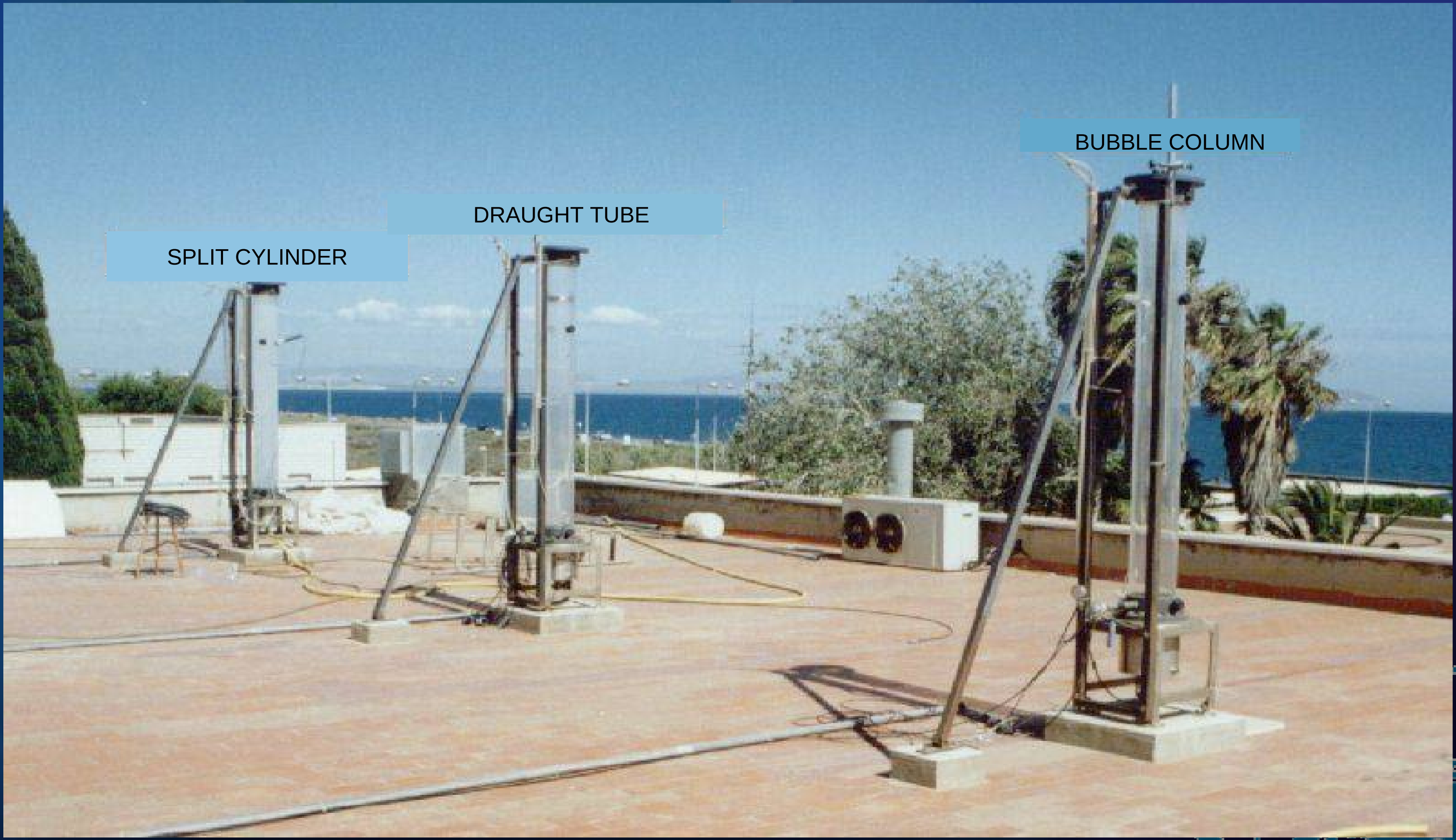
- Flat plate

Bubble column type photobioreactors (1)



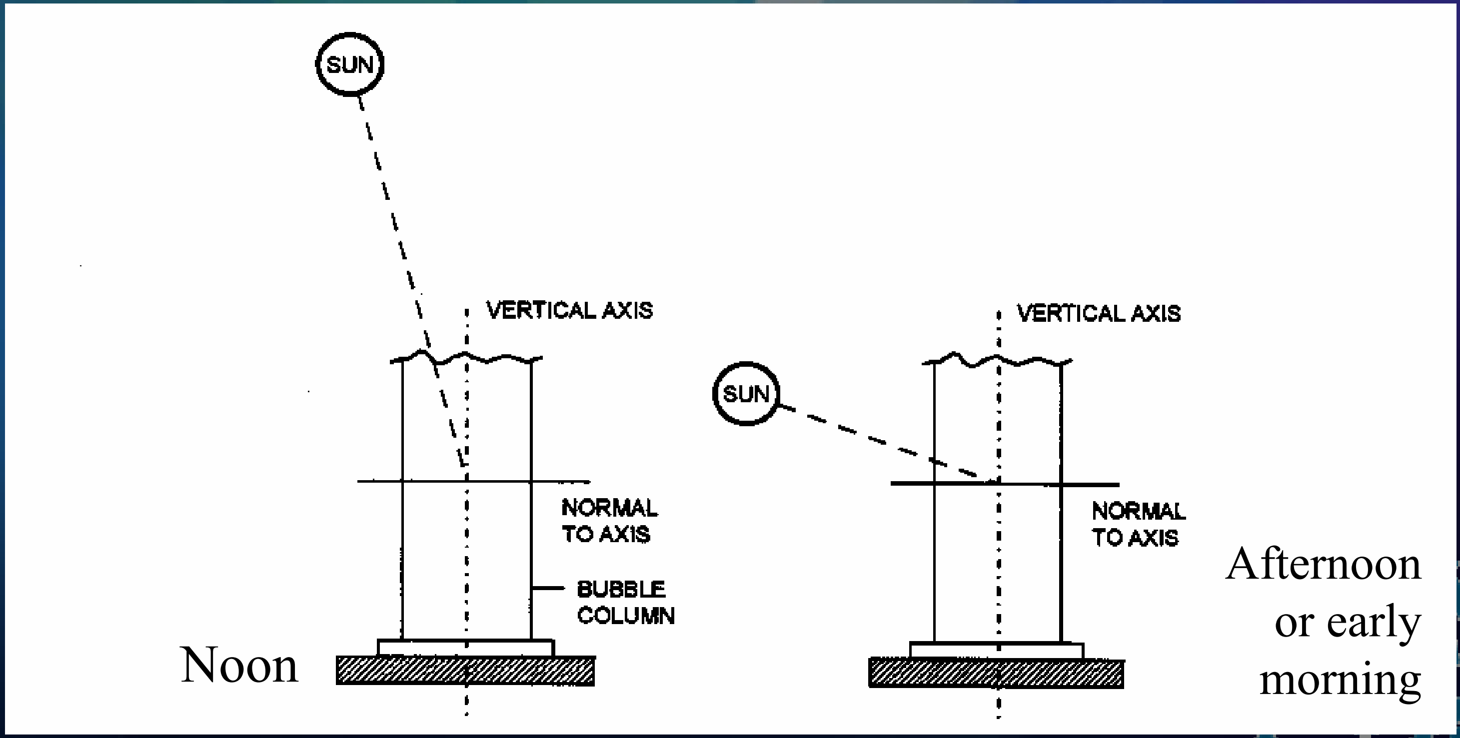
Sánchez Mirón et al., 2000 Aiche Journal, 46, 1872-1887

Bubble column type photobioreactors (2)



Bubble column type photobioreactors (3)

- Height of only a few meters
- Major advantage: oxygen does no accumulate
- Easy to keep sterile compared to other tubular systems
- Major drawback: the reactor is always at a large angle to the sun's rays

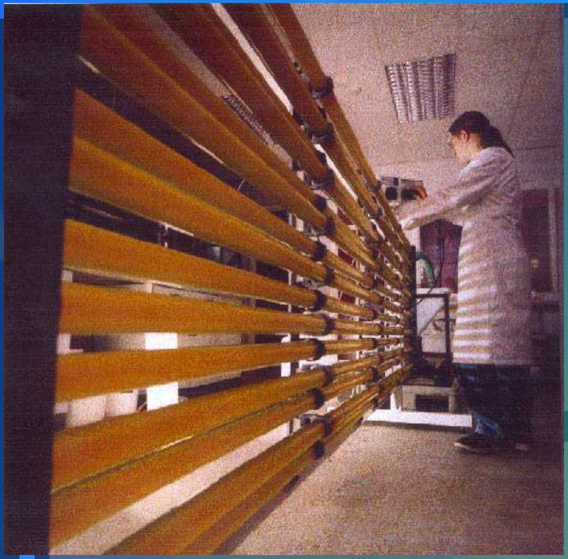


The amount of solar energy absorbed is lower than for horizontally placed reactor

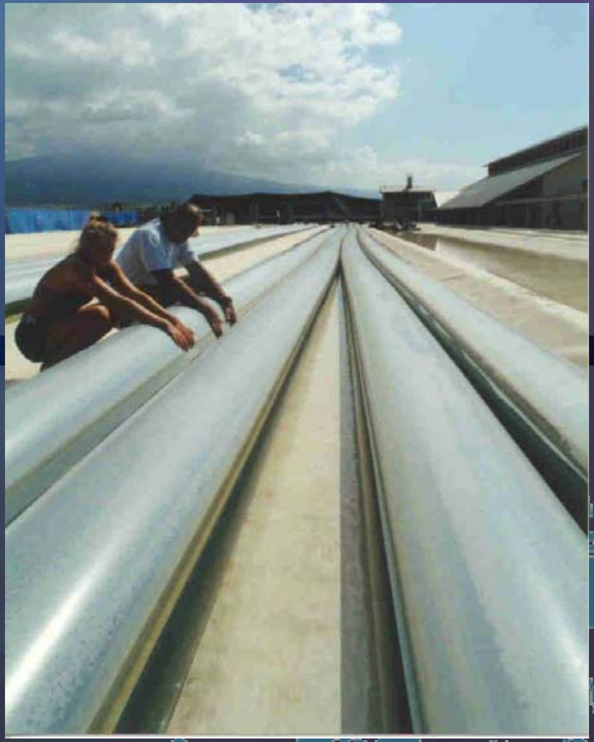
Tubular photobioreactor (1)

- Solar loop: arranged to optimally harvest sunlignt.
- Solar loop: arranged to minimize land occupation
- Airlift system: adequate pumping and effective gas removal

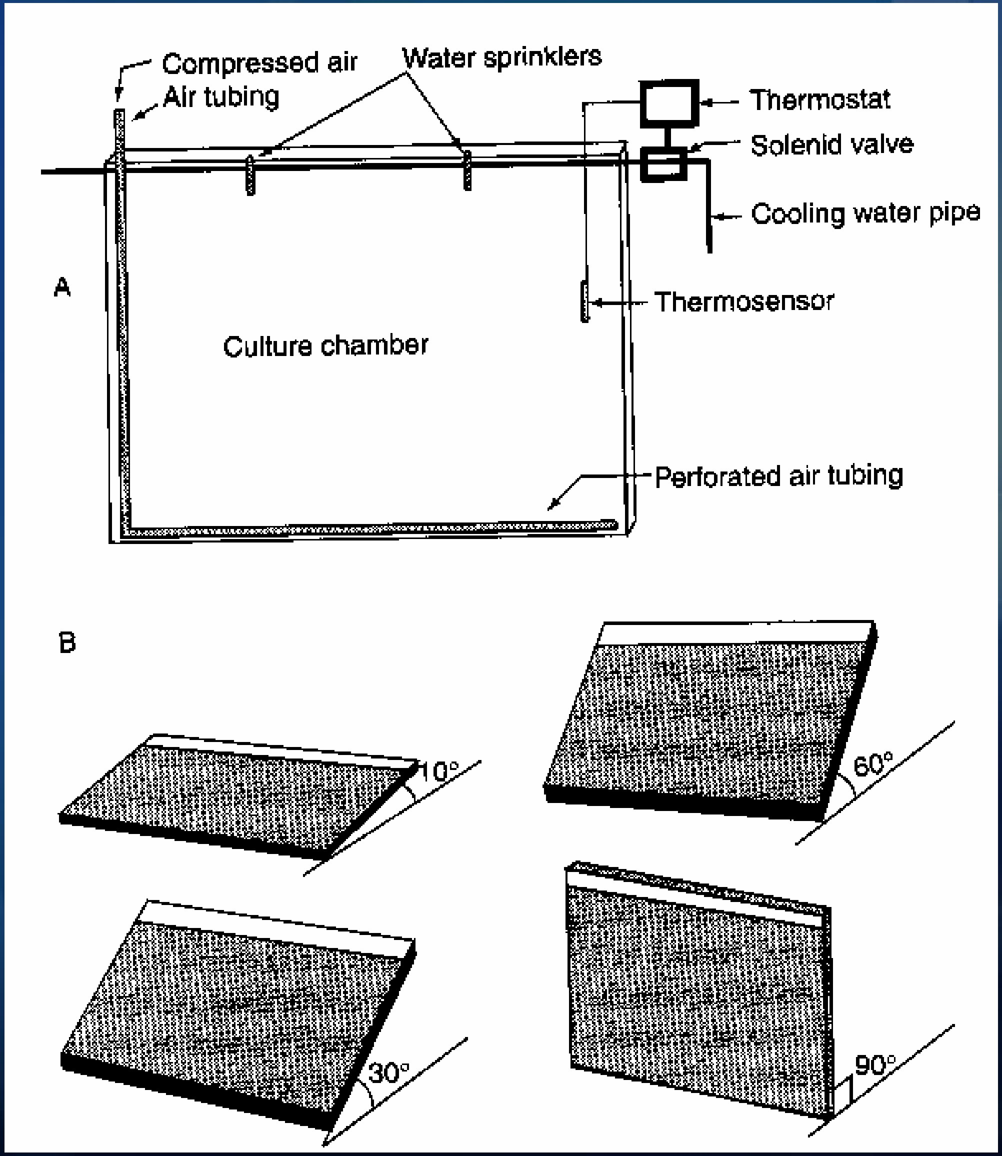
Tubular photobioreactors (2)

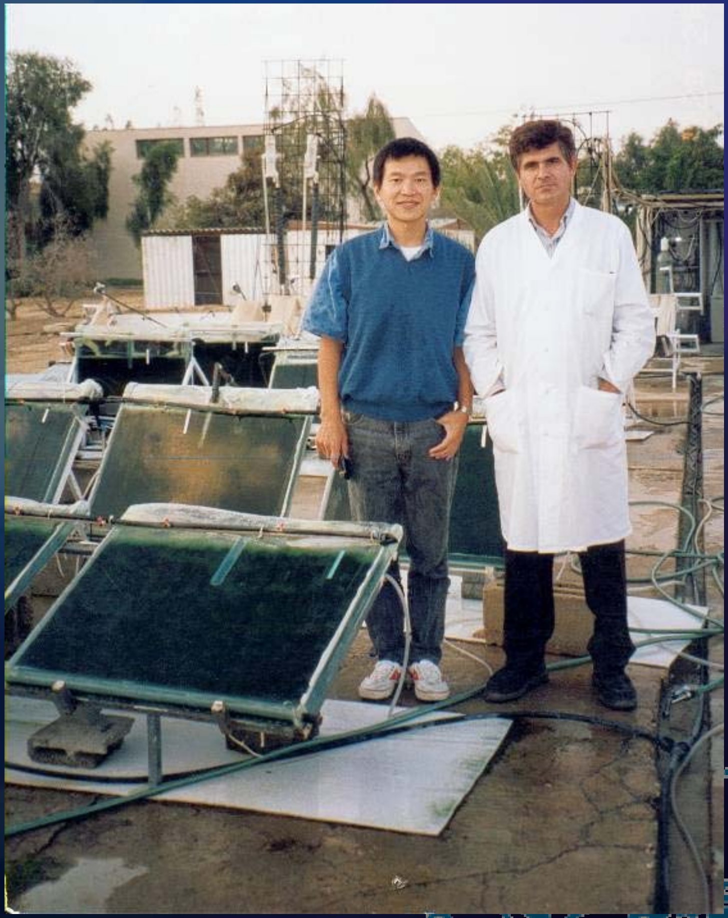




Flat plate reactors (1)





Flat plate reactors (2)

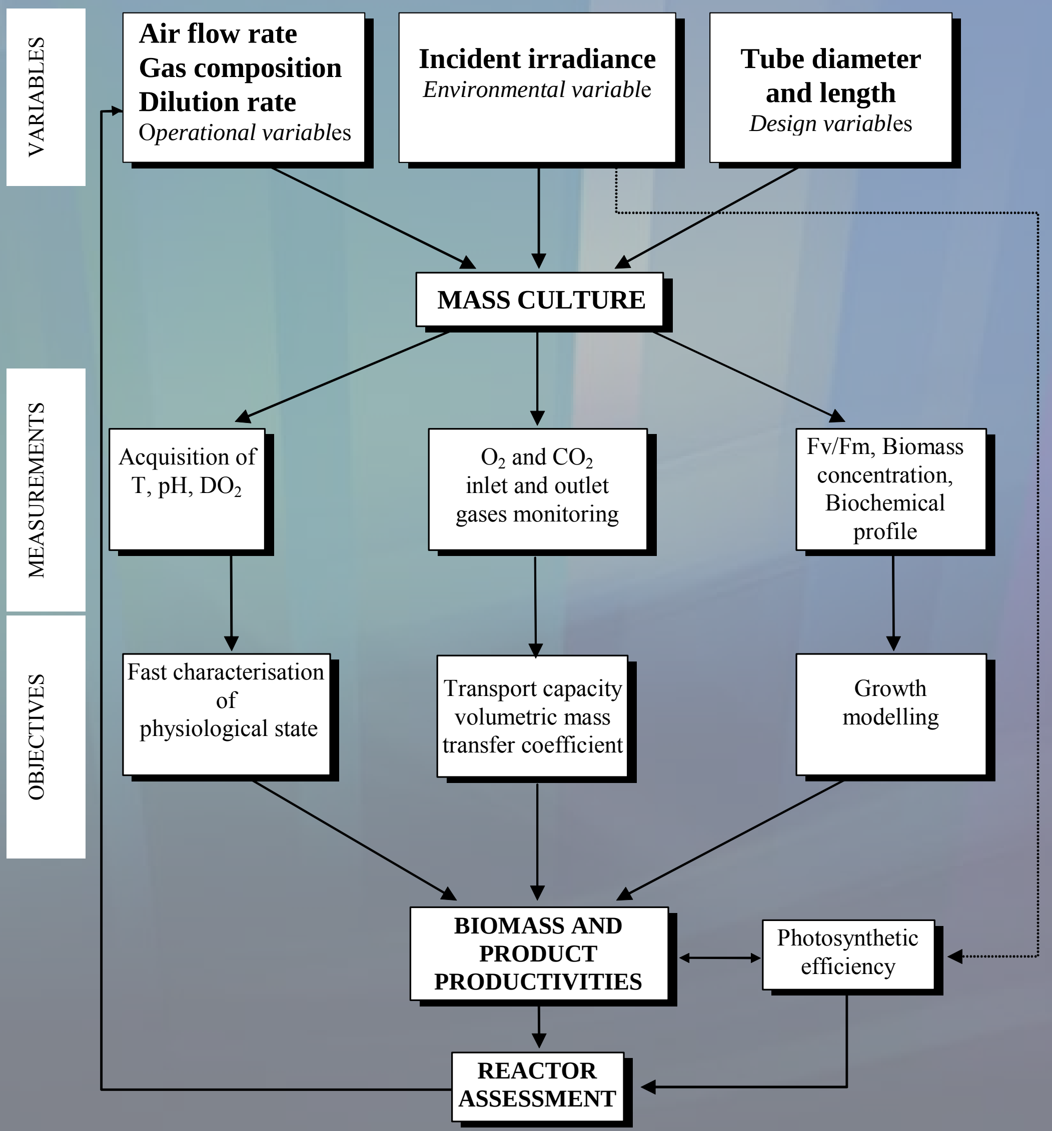
Flat plate reactors (3)

Drawback •Difficulty in maintaining an adequate turbulence, buidup of O_2 (up to 30-40 mg L^{-1}); fouling

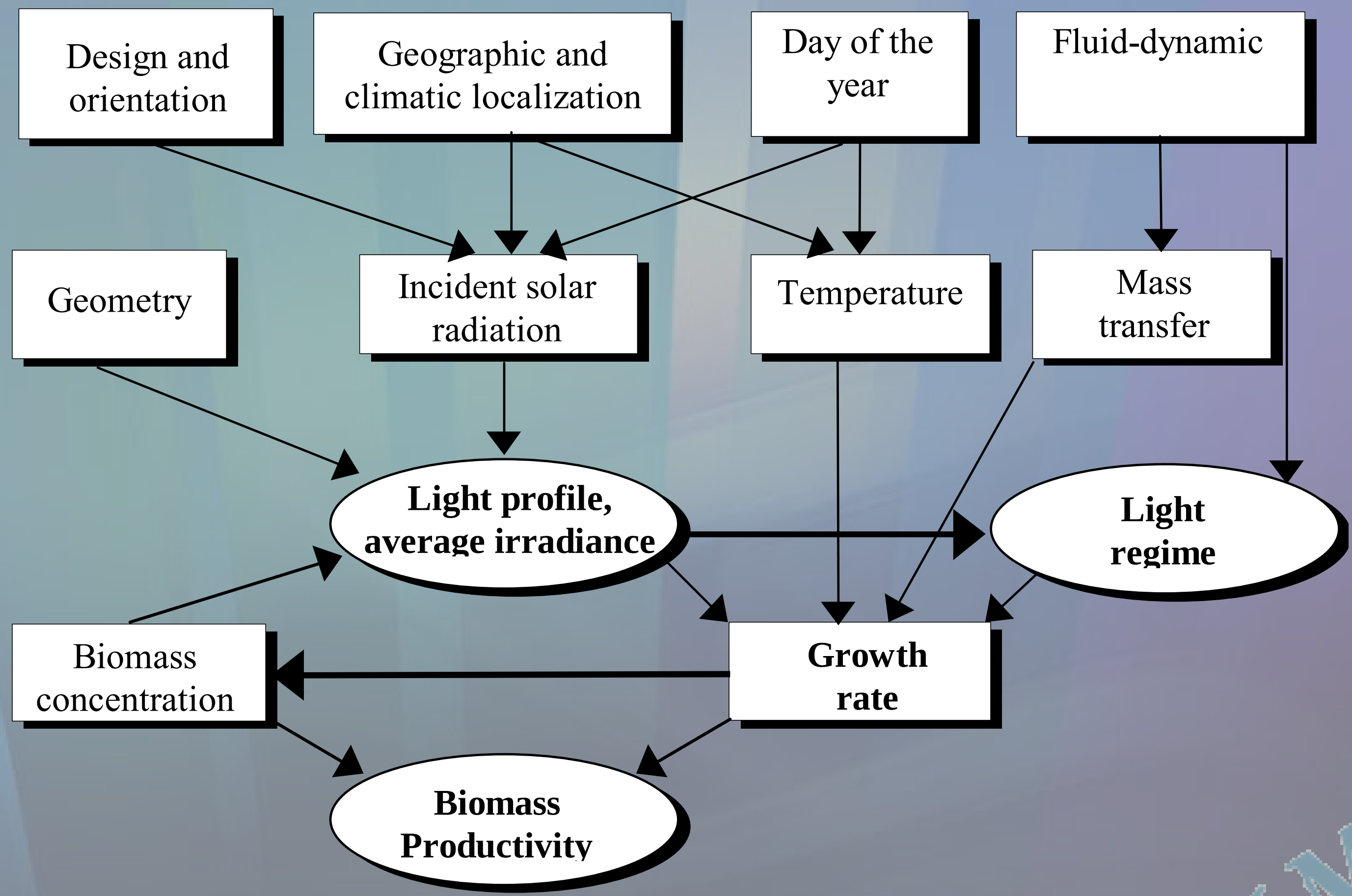
Merit •Illuminated surface over 500 m^2 could be set up on a ground area of 100 m2

•Lamination of irradiance →enhancement of light efficiency

Main variables to be assessed and their impact on the reactor's performance



Relationship among parameters that influence biomass productivity



E. Molina Grima 1999, Encyclopedia of Bioprocess Technology: Fermentation, biocalysis and Bioseparations. 1753-1769, John Wiley and Sons Inc.

Design of tubular reactors

Design strategy (1)

Biomass productivity must be optimized.

$$Pb_v = \mu \cdot C_b$$ g L^{-1} d^{-1}

$$\mu = \frac{\mu_{max} \cdot I_{av}^n}{I_k^n + I_{av}^n}$$

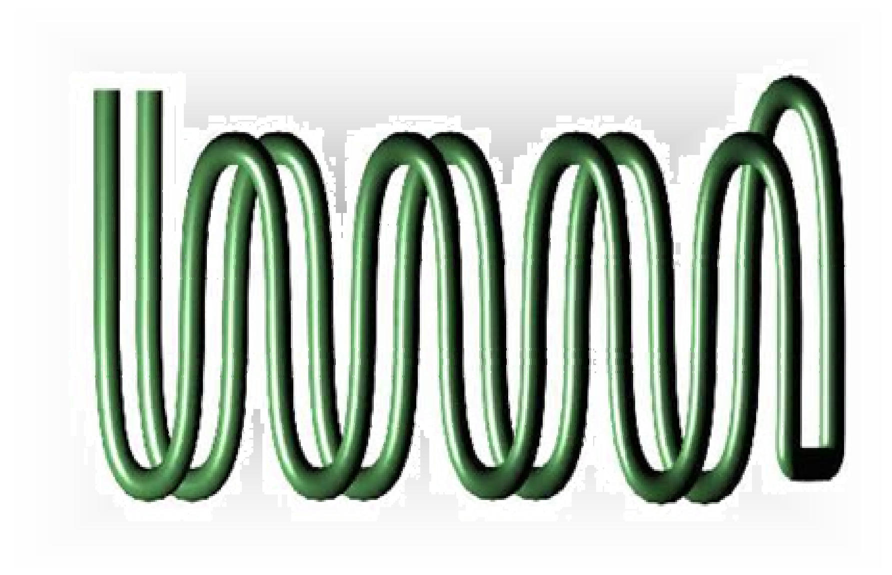
$$I_{av} = \frac{I_o}{\phi_{eq}}\left(1 - \exp(-\phi_{eq} \cdot K_a \cdot C_b)\right)$$

$$\phi_{eq} = \frac{d_t}{Cos(\theta)}$$

$$Pb_a = Pb_v \frac{\pi \cdot d_t}{4 \cdot n_T}$$ g m^{-2} d^{-1}

Design strategy (2)

- ✓ I_o must be maximized.
  - ✓ I_o=f(location, weather, geometric arrangement)
- ✓ The arrangement of tubes controls the mutual shading.
- ✓ Maximizing land use



Design strategy (3)

- Liquid velocity

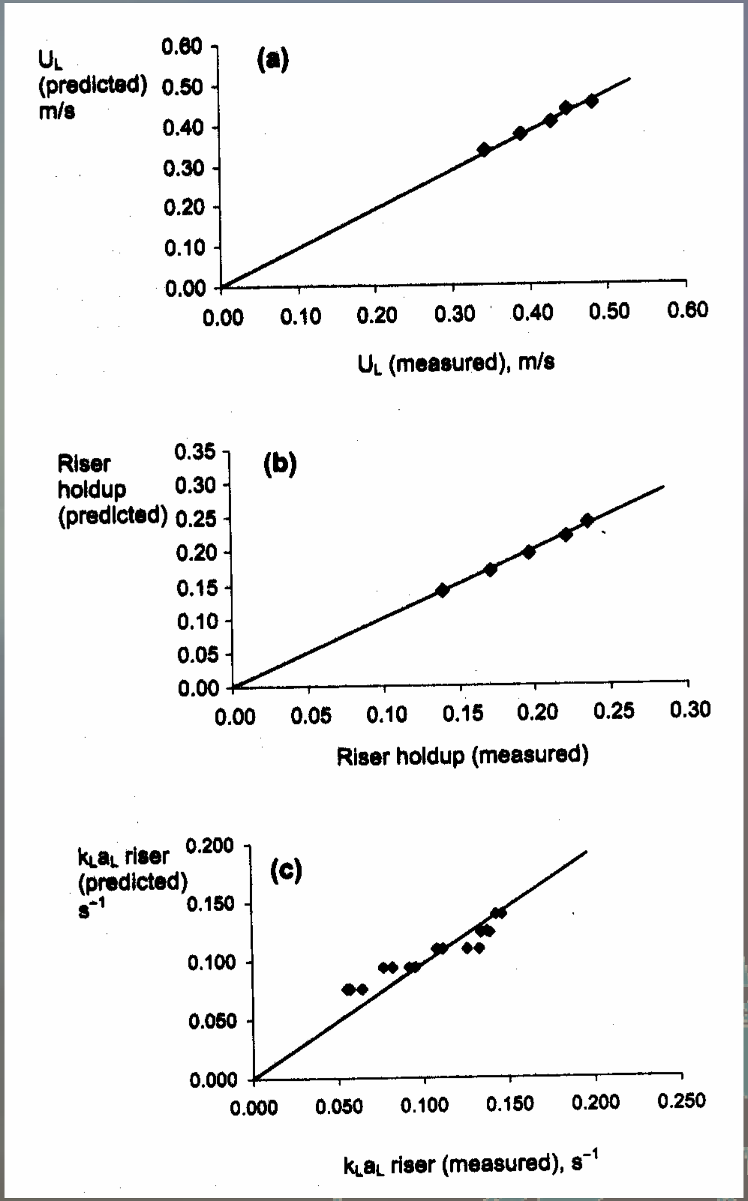
$$U_L = \left(\frac{g \cdot \varepsilon_r \cdot h_r \cdot d_t^{1.25}}{0.316 \cdot \left(\frac{\mu_L}{\rho} \right)^{0.25} \cdot L_{eq}} \right)^{4/7}$$

- Gas holdup

$$\varepsilon_r = \frac{\beta}{\lambda + \frac{u_b}{u_g + u_L}}$$

- $K_L a$

$$\frac{k_L}{d_b} = \frac{k_L \cdot a_L}{6 \cdot \varepsilon_r} (1 - \varepsilon_r)$$



Design strategy (4)

- ✓ The maximum continuous run length of the solar tube is limited by a combination of factors.

$$L = \frac{u_L\left([O_2]_{in} - [O_2]_{out}\right)}{RO_2}$$

Design strategy (5)

- The airlift system should satisfy the principal demands:
  - •Effective circulation of the fluid
  - •Effective separation of gas and liquid

$$L_D = \frac{\pi}{4} \cdot \frac{d_t \cdot u_L}{u_b}$$

- The airlift system should be small

Design strategy (5)

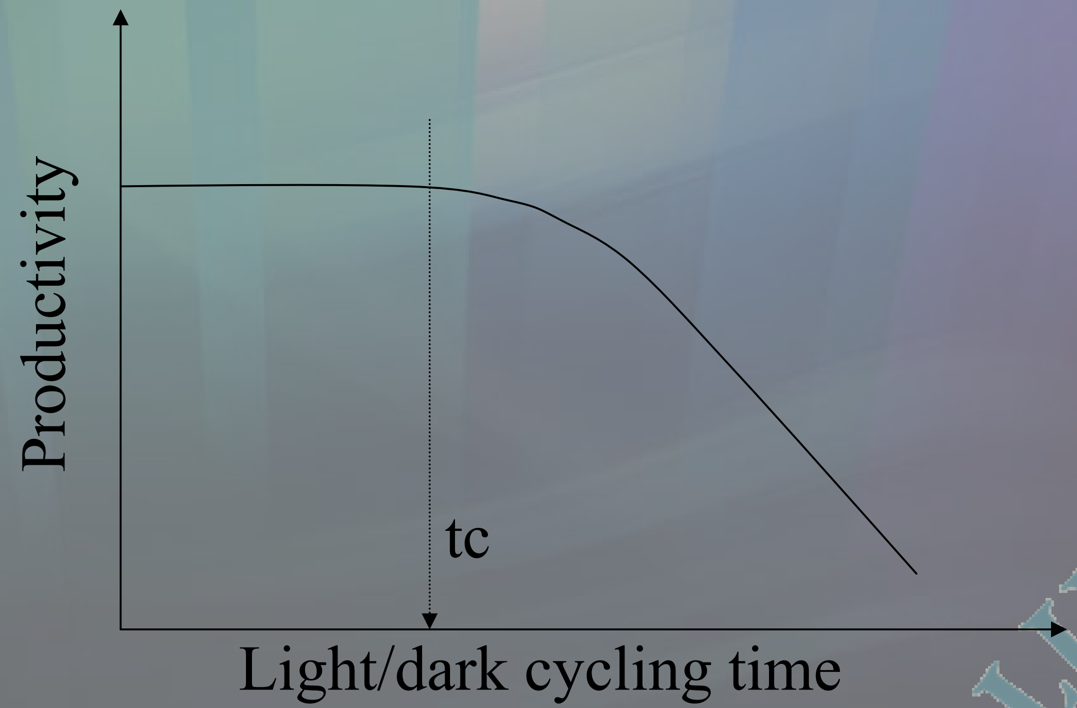
Scaleup approaches

$$V = \frac{\pi \cdot d_t^2}{4} \cdot L$$

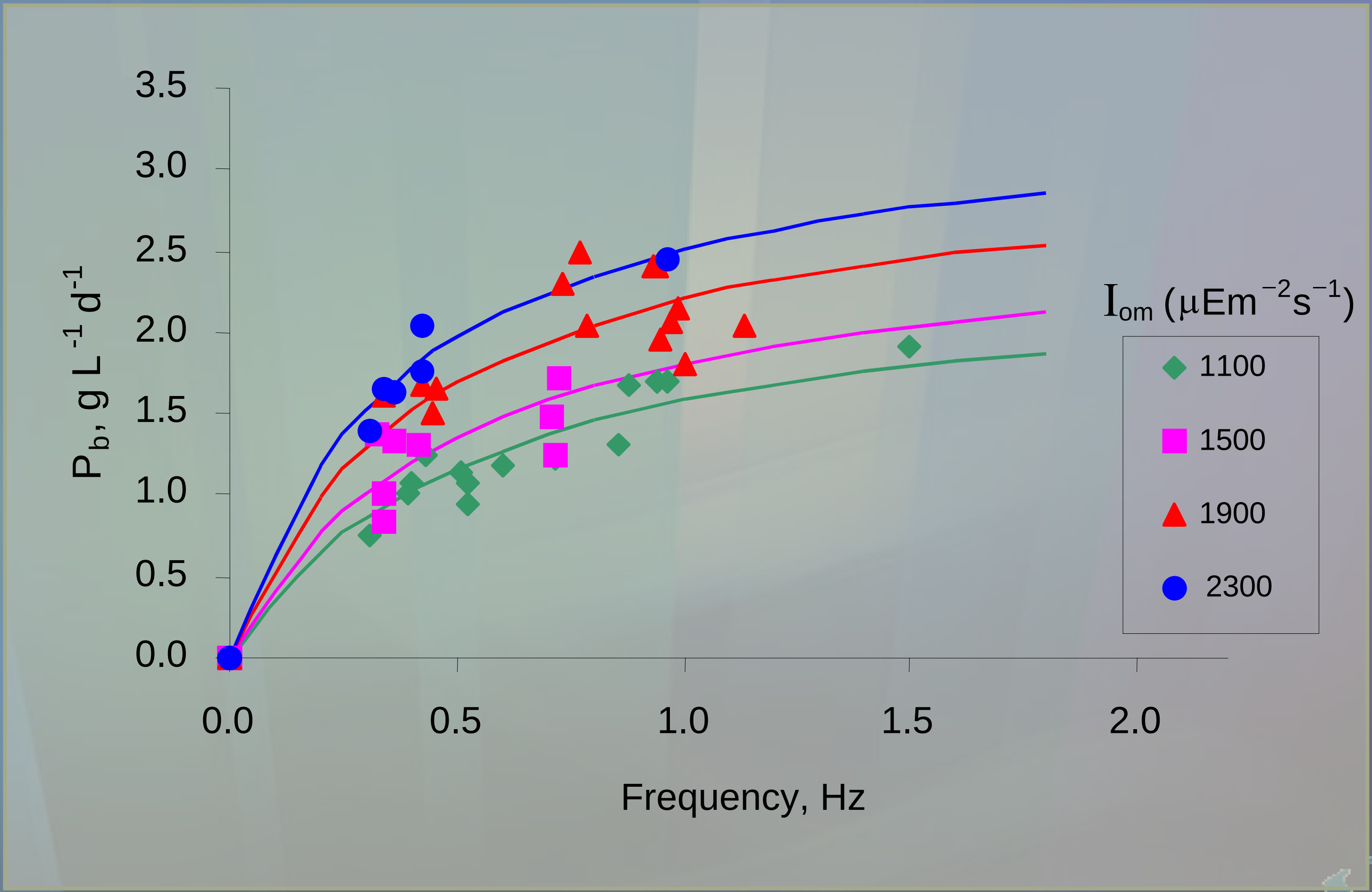
- The only variable that can be scaled up is d_t
- d_t determines the tube length
- Then, multiple modules of identical type

The scaleup criterion

- The frequency of the light/dark cycle interchange is held constant upon scale up.

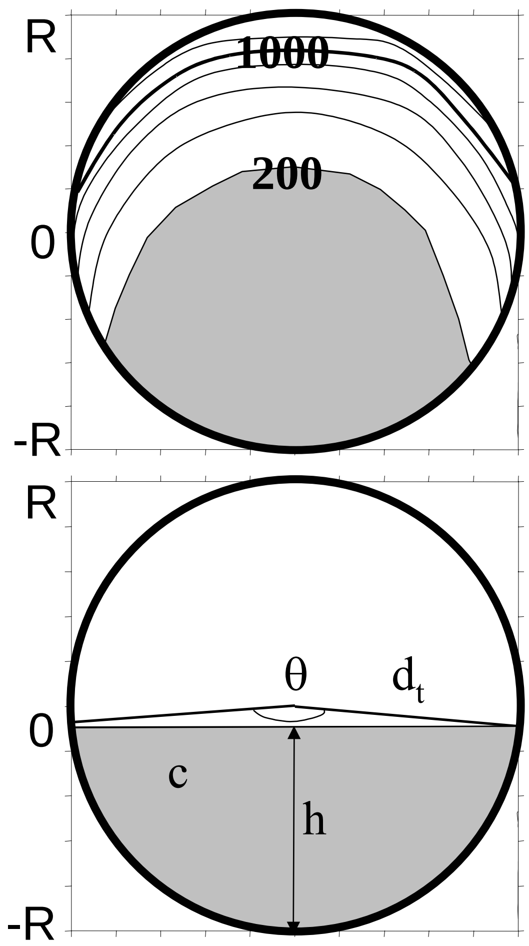


Scaleup considerations



E. Molina Grima et al. (2001) J. Biotechnol 92, 113-131

The scaleup criterion



$$Q_R = \frac{\text{Dark zone volume}}{t_d}$$

$$U_R = \frac{Q_R}{\text{Surface}}$$

$$\Phi = \frac{V_f}{V_f + V_d}$$

$$\nu = \frac{1-\Phi}{t_d}$$

http://www.ual.es/Universidad/Depar/IngQuimi/contenido/I(r).htm

The scaleup criterion

$$\boxed{\frac{d_{tL}\,U_{RS}}{a\,d_{tS}\,U_{RL}} = 1} \Rightarrow U_{RL} = \frac{f}{a} U_{RS}$$

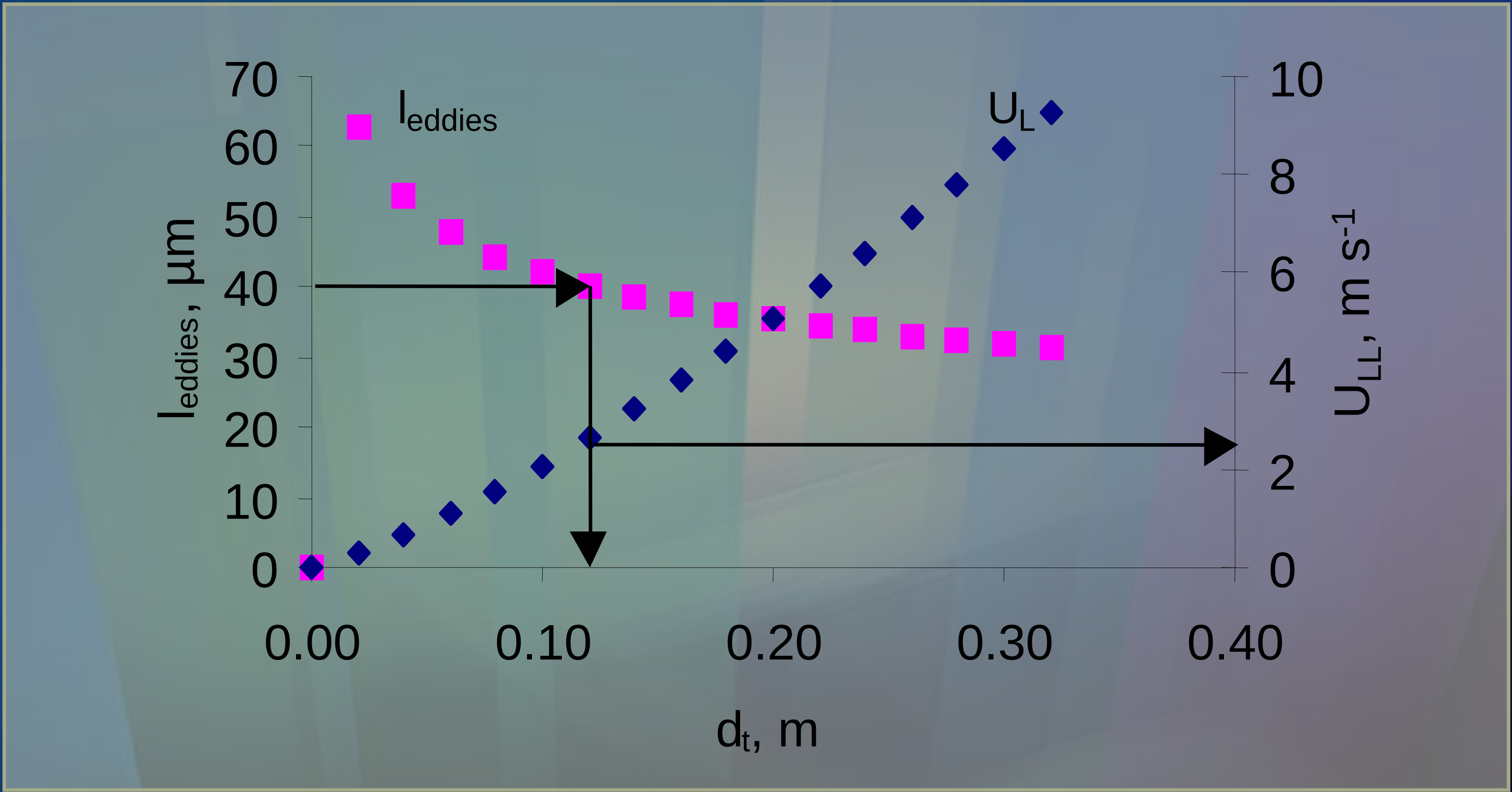
$$f = \text{scale factor} = \frac{d_{tL}}{d_{tS}}$$

$$a = \frac{1-\Phi_L}{1-\Phi_S}$$

$$U_R = 0.2\,\frac{U_L^{7/8}\,\nu^{1/8}}{d_t^{1/8}}$$

$$U_{LL} = \frac{f^{9/7}}{a^{8/7}} U_{LS}$$

Maximum scaleable tube diameter



$$u_{ll} = \frac{f^{9/7}}{a^{8/7}} \cdot u_{ls}$$

Contreras et. al (1998), Biotechnol. Bioeng. (60) 317-323

$\lambda < 45\ \mu m$, $\gamma > 7000\ s^{-1}$ } Harmful to P. Tricornutum cells

C. Brindley Alias et al. (2004) Biotechnol Bioengng., in press.

The industrial-scale reactor and the microalgal production system

The industrial-scale reactor and the microalgal production system

cajamar

XV Juegos Mediterráneos
Almería 2005

MINISTERIO
DE EDUCACION
Y CIENCIA

Departamento de Ingeniería Química

Universidad de Almería