Overcoming Shear Stress of Microalgae Cultures in Sparged Photobioreactors

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Abstract: In the present work we identified and quantified the effect of hydrodynamic stress on two different microalgae strains, *Dunaliella tertiolecta* and *D. salina*, cultivated in bench-scale bubble columns. The cell death rate constant increased with increasing gas-entrance velocity at the sparger. *Dunaliella salina* was slightly more sensitive than *D. tertiolecta*. The critical gas-entrance velocities were ~50 and 30 m s^{-1} for *D. tertiolecta* and *D. salina*, respectively. The effects of gas-flow rate, culture height, and nozzle diameter on the death rate constant were also studied. From these results it was concluded that bubble rising and bubble bursting are not responsible for cell death. Regarding nozzle diameter, small nozzles were more detrimental to cells. The bubble formation at the sparger was found to be the main event leading to cell death. © 2004 Wiley Periodicals Inc.

Keywords: microalgae; bubble column; hydrodynamic stress; cell death

INTRODUCTION

Power input is necessary in sparged photobioreactors, such as bubble columns and flat panels, for mixing, heat elimination, and mass and light transfer. Its importance increases with scale-up. However, it can also lead to shear, which can result in impaired cell growth, cell damage, and eventually cell death.

High superficial gas velocities are desirable in microalgae cultivations in order to create a high degree of turbulence allowing a fast circulation of the cells from the dark to the light zone of the reactor. These fast liquid-circulation times (on a μ–ms scale) have been shown to give rise to considerable higher photosynthetic efficiency (Kok, 1953; Matthijs et al., 1996) than longer cycles, which can even lead to a decrease in the photosynthetic efficiency (Janssen et al., 2000, 2001). Janssen et al. (2002) reported that the average liquid circulation time in vertical bubble columns will be between 0.5–2 sec at superficial gas velocities of 0.05 m s^{-1} or higher. These calculations were based on the model of Joshi and Sharma (1979). Very high superficial gas velocities are thus required in order to achieve high productivities in bubble columns.

According to Gudin and Chaumont (1991), the key problem of microalgae cultivation in photobioreactors is cel damage due to shear stress. However, few quantitative studies have been done to characterize algal cells with respect to their shear sensitivity, and within these few works, very different types of equipment, methodology, and reactor configurations have been used (Bronnemeier and Markl, 1982; Silva et al., 1987).

The growth rates of some microalgae have been reported to increase initially with increasing turbulence, probably due to the improved supply of CO_2 or light. But upon an optimum level of turbulence, the growth decreases sharply with further increase of the superficial gas velocity (Silva et al., 1987; Merchuk et al., 2000, Suzuki et al., 1995). These results, i.e., an increase in cell damage with increasing superficial gas velocity, led to the conclusion that algae death was mainly due to the bursting of bubbles at the surface. But in reality, it could also have been due to bubble formation, as further explained and discussed below.

The effect of hydrodynamic forces generated by air bubbles on animal cells in suspension has been extensively studied (Chalmers, 1996; Tramper et al., 1988). Tramper et al. (1986) distinguished three regions in a bubble column where cell death might occur: 1) at the sparger where the bubbles are formed, 2) in the region where the bubbles rise, and 3) at the surface where bubble disengagement occurs.

Cell death rate can be described by first-order kinetics as described by Eq. (1), provided that the cell growth rate is zero or negligible compared to the cell death rate:

$$\ln\left(\frac{C_{Xv}(t)}{C_{Xv}(0)}\right) = -k_d \cdot t \qquad (1)$$

where $C_{Xv}(t)$ and C_{Xv} (0) are the viable cell concentration (cell m^{-3}) at time $t = t$ and $t = 0$ (h) respectively, is the first-order death rate constant (h^{-1}) and t is the time (h).

Tramper et al. (1988) proposed a model for cell damage caused by sparging in which a hypothetical killing volume

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